SCIENCE

A Textbook for Class IX

Part I

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~~Back Cover~~ · Edward Jenner (1749-1823) who prepared smallpox vaccine from cowpox virus, is inoculating his own son
(from an old engraving)

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Foreword

The teaching of science as a part of general education up to Class X has been re-emphasized in the 'National Policy on Education—1986'. Soon after adoption of the National Policy on Education—1986, the task of developing curriculum and related instructional materials in science and mathematics was entrusted to the Department of Education in Science and Mathematics (DESM) of NCERT. To begin with, the DESM developed a draft of the guidelines for science education for the upper primary and secondary classes keeping in view [illegible] of the National Policy on Education and the Curriculum Framework.

The present textbook for Class IX is based on the syllabus developed by the Department of Education in Science and Mathematics, NCERT. The syllabus was finalised after incorporating comments and suggestions received from a large number of scientists, subject experts, teacher-educators, teachers and Associations of teachers.

The programme of developing instructional materials in science and mathematics for the upper primary, secondary and senior secondary stages was entrusted to an Advisory Board with Prof C. N. R. Rao, Director, Indian Institute of Science, Bangalore as its chairman Dr D Balasubramanian, Deputy Director, Centre for Cellular and Molecular Biology, Hyderabad, acted as the Chairman of the writing team and editorial group for the secondary stage. The draft manuscript of the textbook developed by the writing team was reviewed in a workshop which was attended by teachers, teacher-educators and subject experts. The manuscript was then revised and edited to its present form.

I take this opportunity to thank all members of the writing team, specially Dr D. Balasubramanian (CCMB), Chairman of this writing team and Shri K. B. Gupta, Coordinator of this programme

My special thanks are due to Prof P M Bhargava, Director, Centre for Cellular and Molecular Biology, Hyderabad and his colleagues for extending all facilities and hospitality during the development of this textbook. Thanks to Prof. B. Ganguly, Head, Department of Education in Science and Mathematics, NCERT, for his keen interest and active guidance at all stages of this work. Last but not the least I would like to thank all participants of the review workshop for their valuable comments and suggestions and also the faculty members of the DESM in the writing team who have been associated at all stages of development and printing of this textbook.

In the end, I would like to mention that this is the first effort for developing this kind of science textbook where a new approach has been adopted. The authors, reviewers and editors had very little time at their disposal to bring out the textbook Suggestions and comments towards the improvement of this textbook would be most welcome.

P L. MALHOTRA
Director
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Preface

The textbook of Science for Class IX is based on the National Policy on Education (1986), National Curriculum for Primary and Secondary Education a Framework (1986-87), and guidelines and syllabus developed earlier.

It was a challenging task for us in the writing team to write a textbook of Science different from the traditional format The task was to integrate all disciplines of science in a natural fashion. An attempt has been made to create a genuine amalgamation of facts, figures and data from different disciplines. The learning experiences of students in earlier classes have been taken as prerequisite and the aim has been directed towards the further development of the abilities of problem-solving and creative thinking It is hoped that this textbook will promote the growth of interest and curiosity among children to know more about scientific principles so that they are able to understand and appreciate natural phenomena which do not come classified as physics, chemistry and biology. Efforts have been made to give more activities to facilitate learning If the book appears to be heavy, it is because we feel that clarity should not be sacrificed for brevity. We hope we have succeeded in the task This book should be considered as an attempt towards such a direction It contains five units Matter, Motion, Force and Energy, Ways of Living, Human Beings; and World of Work.

The five units of the syllabus have been arranged into different chapters in the textbook Each chapter begins with an introduction which gives an overview of the content and the scope of the chapter, besides its linkage with other chapters. Efforts have been made to present the concepts in a simple and interesting manner Wherever desirable, additional and interesting information has been provided in a box or in a table. The intention is not to burden the students with more content but to arouse their curiosity for further learning A large number of activities have been suggested either as a student activity or as a teacher demonstration. These activities are not meant to be prescriptive but may be modified, adapted or even replaced, keeping in view the experiences and environment of the students or the resources available Each chapter includes questions at the end. In some chapters a special section titled 'In the language of mathematics' has been included to familiarise the students with various symbols, equations and formulae.

An overall improvement of science education would not be possible only through textbook It will depend on how the education has been transacted. For this reason, the teacher must read the entire textbook and plan his/her own teaching strategies so that lesson plans are developed from the textbook. Teachers may replace some of the activities with their own innovative ones. It is hoped that a major part of teaching-learning process would be devoted to activities and the teacher will intervene at appropriate places to reinforce learning. Teachers are hence requested to examine the syllabus and other documents developed earlier so that they can get a proper perspective of the material.

The authors would welcome comments and suggestions from classroom teachers which would help in the subsequent improvement of this version.

The Chairman of the writing team is thankful to a large number of people for developing this manuscript. Prof C N. R Rao, Director, Indian Institute of Science, Bangalore has been a source of advice and help The Chairman is specially thankful to Dr P. M Bhargava, Director, Centre for Cellular and Moleculer Biology, Hyderabad and his other colleagues of the CCMB, for their ready cooperation and generous help during the development of this book. Indeed CCMB threw open all its facilities to the Chairman and to the working group. This made us win the race against time Thanks are due to Dr P L. Malhotra, Director, National Council of Educational Research and Training (NCERT), for his interest and in particular to Prof B Ganguly, Head, Department of Education in Science and Mathematics, NCERT, for his continual help in developing the manuscript All the participants of the workshop organised to review the manuscript of this book deserve special thanks for their valuable suggestions and critical comments

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NOTE

Part II of this book for Class IX will comprise Chapters 15-21

CHAPTER 1

THE NATURE OF MATTER

INTRODUCTION

WE SEE an enormous variety of plants, animals and many other objects around us. No two plants, no two animals, no two hills are identical Even two leaves from the same tree are not totally identical No two human beings are exactly alike. Truly, *nature has an unlimited* variety of living and non-living objects

How is this variety produced? Does nature have an unlimited, enormously large storehouse containing infinite ingredients? Man has always been curious to know. Several attempts have been made to understand this variety The Greeks and Indians thought that the wide variety of objects around us are made of five basic elements, namely, earth, fire, water, air and sky. The Indian sage Kanada suggested that all matter is composed of very small particles. Interestingly, all these guesses had one common feature: the understanding that a large variety could be generated from just a few building blocks. It is likely that this guess was based on man's experience of a limited number of alphabets producing many words and an unlimited number of sentences, a few ingredients in the kitchen from which a large number of dishes could be prepared, a few basic colours mixed in different proportions producing a wide range of shades and a few basic notes producing a rich variety of music.

If we are to attempt to explain this wide variety, our explanation must be simple, complete and elegant. In addition, it should give us an insight—that is, it should help us to understand what we observe. Most importantly it should enable us to predict what we would see if we conducted an experiment You will understand this point better as you study this chapter.

1.1 Dalton and Atomic Theory

Starting from around seven centuries ago, scientists were busy conducting experiments with a variety of substances. They were trying to find a method for converting cheap and readily available metals like lead and copper into precious and expensive gold In these experiments, they tried all the methods they knew—mixing, heating and separating materials. They could not succeed in making gold. But in the process, they generated and carefully recorded a wealth of information, which helped to develop our understanding of nature. You must not smile at these early experiments; they have contributed (knowingly or unknowingly) much to science.

People who simply observed nature, collected specimens and classified them were called naturalists. They helped to develop biology. Early astronomers mapped the sky and carefully noted the positions of stars. Sailors who kept detailed records of their long voyages helped to develop maps. All these people were careful observers, who kept a detailed and accurate record of what they observed. Science owes much to these people. We shall learn more about such people as we go along.

The early experiments in chemistry consisted only of mixing and heating substances at random Later careful quantitative measurements began to be made For example, if the substances were made of copper and oxygen, the experimenters carefully studied the proportion of these two components by weight Quantitative relationships of chemistry emerged, helped later scientists For example, Dalton studied the composition of several compounds. He found that no matter which sample of a particular substance was chosen, the proportion by weight of its elementary constituents remained the same For example, water taken from any place is composed of hydrogen and oxygen. The proportion in it by weight of hydrogen to oxygen is always 1·8. He called this the law of constant proportions.

He also found that the constituents can combine in several ways to form different substances These substances have different physical and chemical properties Thus, for example hydrogen and oxygen combine in two different ways to produce water and hydrogen peroxide. In water 1g of hydrogen combines with 8 g of oxygen. And in the other compound of hydrogen and oxygen, namely, peroxide, 1g of hydrogen combines with 16g of oxygen The ratio of oxygen combining with the same amount of hydrogen, i.e. 1g is 8,16 or 1:2 between water and hydrogen peroxide—a small integral ratio. Dalton called this the law of multiple proportions.

He deduced a very simple picture from all this complexity. He proposed the following·

1. All matter is made of very tiny particles which cannot be broken down further. He called these tiny particles—atoms. (Tomio in Greek means to divide or break.) Atom, therefore, means non-divisible (A-tomio).
2. An element is a substance that has the same kind of atoms in it that is, all atoms of an element are identical
3. Atoms of elements combine in many ways to create the variety and complexity we see around us.

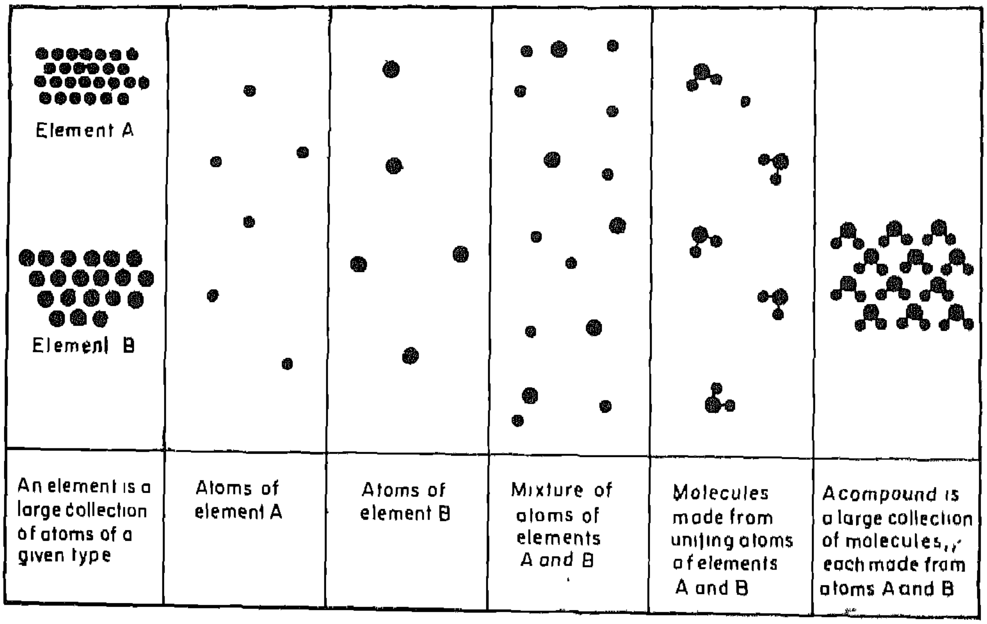
Thus, according to Dalton, hydrogen gas is composed of atoms of hydrogen, while oxygen gas is composed of atoms of oxygen. Two atoms of hydrogen combine with one atom of oxygen to produce water. It is not surprising, therefore, that the weights of hydrogen and oxygen will always be in the same proportion in water, irrespective of its source.

When two atoms of hydrogen combine with two atoms of oxygen to form hydrogen peroxide, the proportion of oxygen atoms combining with hydrogen will simply double when compared to water Very simple, is it not?

Elements are substances made of only one type of atoms. Hydrogen, oxygen, silver, copper are examples of elements There are also substances made of more than one kind of atoms combined together These substances are called compounds Water is made of hydrogen and oxygen, carbon dioxide is made of carbon and oxygen, sugar is made of carbon, oxygen and hydrogen, and common salt is made of sodium and chlorine Water, carbon dioxide, sugar and salt are compounds. Most materials we come across in nature are mixtures of elements and compounds in various proportions For example, air is a mixture of elements such as oxygen, nitrogen, argon and compounds such as carbon dioxide and water No wonder we get such rich variety Figure 1 1 schematically illustrates elements, compounds and mixtures

Exercise 1

You are aware that we come across objects of several shapes Let us take two simple shapes· (1) A circle, and (2) an equilateral triangle. How many different shapes can you generate using these two shapes? If you are allowed to use (1) a



An element is a large collection of atoms of a given type

Atoms of element A

Atoms of element B

Mixture of atoms of elements A and B

Molecules made from uniting atoms of elements A and B

A compound is a large collection of molecules, each made from atoms A and B

Fig 1.1 *An element is a large collection of atoms and a compound is a large collection of molecules*

circle, and (2) any triangle, can you generate some more shapes? Can you draw a shape which cannot be generated if you are restricted to use only equilateral triangles?

In nature oxygen is found in the form of oxygen molecules. Similarly, many other elements exist in molecular form and not as free atoms Only elements known as rare gases are found in the free atomic form.

You know that atoms of the same kind can combine to form a molecule. Thus, two atoms of oxygen combine to form an oxygen molecule

Now can you say which of the following statements is more correct? Why?

1 Two atoms of hydrogen combine with one atom of oxygen to give one molecule of water
2 Two molecules of hydrogen combine with one molecule of oxygen to give two molecules of water.

Why are some elements in molecular form while others are in atomic form?

While Dalton's theory explained many things and enabled us to interpret several observations (complexity, laws of chemical combinations), it could not explain everything. For example, charcoal, graphite and diamond are all composed of carbon atoms. Why then should their properties be so different? The atoms as conceived by Dalton was not able to provide an answer.

There was yet another problem Scientists could produce simple compounds like water, carbon dioxide, hydrogen chloride or sulphuric acid in the laboratory. However, many molecules like urea or sugar found in living organisms, could not be synthesised These compounds were found in living organisms. Hence, some scientists felt that the vitality of the living organism was necessary to form these compounds. However, some other scientists did not like this explanation The concept of chemical affinity was proposed for explaining why some reactions take place while others do not (sulphur has an affinity for oxygen but no affinity towards nitrogen) Can you tell what is wrong with these explanations? They lack the ability to predict

John Dalton had assumed that the atom was not divisible, i e., it was not composed of simpler constituents Dalton's atoms were imagined to be like marbles, atoms of different elements differed in mass, and in size, but were otherwise very similar.

1 2 The Structure of Atoms

This picture changed dramatically at the turn of the 19th century Just the twenty-year period from 1895 to 1915 changed so many basic concepts related to atoms and revealed so many new phenomena that man's understanding of the natural world underwent a radical change

In the nineteenth century, scientists were endowed with a new tool called electricity While studying the passage of electricity through matter, they found that metals conduct electricity while many other substances were insulators. When they went on to study the passage of electricity through gases, several new and startling phenomena were observed.

✓ Electricity, passing through a tube containing a gas at low pressure, ~~resulted in~~ the produc-

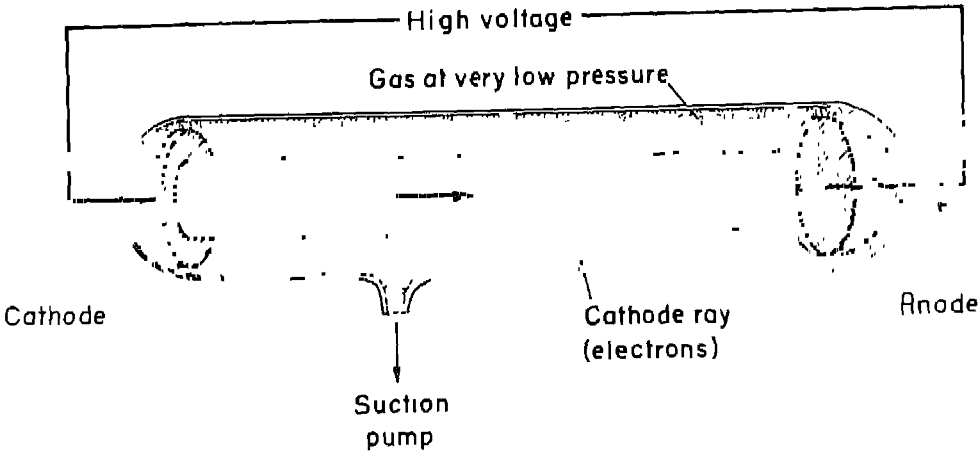


Fig 1.2 *A cathode ray tube Cathode rays are electrons which travel from the cathode to the anode*

tion of new kind of rays (Fig 1 2). These rays, like light, travelled in a straight line, cast shadows of obstacles but, unlike light could be bent by electric and magnetic fields. It was thus clear that these rays consisted of charged particles. Where did these particles come from? To start with, we had only the gas atoms. Do these atoms contain charged particles? In the absence of any clue, scientists called them cathode rays because they seemed to come out of the cathode (the negative electrode)

2. Wilhelm Konard Roentgen (1845-1923) was also studying the passage of electricity through gases. He found in 1896 that when these cathode rays struck the glass walls of the tube a new kind of rays was emitted. These rays travelled in a straight line as light rays do, and could not be bent by an electric or magnetic field They could, however, pass through opaque materials like black paper and expose a photographic plate wrapped in it. Since Roentgen did not know what these rays were, he called them X-rays, just as we use X for an unknown quantity in algebra.

We now know that cathode rays are beams of electrons and that X-rays are electromagnetic waves with very short wavelengths They are emitted when fast-moving electrons are stopped suddenly by some obstruction (as when cathode rays are stopped when they strike the glass walls of the discharge tube).

Very soon after they were discovered, X-rays were used in order to take pictures of bones that have been cracked or fractured. Solid bone stops X-rays from passing through it and is seen as an opaque image in the X-ray film. The fracture between two parts of a bone is thus easily seen in the X-ray picture X-rays are thus an example of how a discovery in basic science can be applied for solving practical problems and becomes technologically useful.

3. Henri Becquerel, a French scientist, tried to find out whether phosphorescent materials emitted any radiation He chose a Uranium salt which was phosphorescent,that is, shines when exposed to light He had kept the minerals and the photographic plate together in his desk for two days. There was no sunlight and therefore he had no reason to believe that the plate would be exposed to light He decided to develop these plates and, to his surprise, found a clear image of the salts placed next to it. He immediately concluded that the salts gave out penetrating radiation spontaneously. This radiation was capable of passing through thick layers of paper.

In 1889 Ernest Rutherford was able to show that this radiation from uranium contained at least two components which he called alpha (α) radiation, and beta (β) radiation Later a French scientist named Villard showed that a third kind of radiation called gamma (γ) rays was also emitted.

Using strong magnetic fields, scientists were able to show that α-rays were positively charged, β-rays were negatively charged while γ-rays carried no charge at all.

Rutherford conducted an ingenious experiment to show that α-rays were actually positively charged helium atoms. He constructed a chamber with a window of thin metal foil. Particles were made to fall on the window. The particles passed through the window and were collected in the chamber Rutherford was able to show that at the end of the experiment, the chamber contained helium gas, even though it had no helium to start with.

4. A systematic study revealed that many minerals emitted radiation which could pass through material like paper. The question now arose—from where are these particles and rays emitted? Obviously, these must come from the atom. It was clear from this new evidence that the idea of an indivisible atom must be abandoned. An atom is divisible

The atom is composed of at least two types of particles, those carrying positive electric charge and those carrying negative electric charge. Moreover, the number of positive and negative charges must be equal in order to maintain the atom as electrically neutral. The negatively charged particles were named **electrons** and the positively charged particles were named **protons**.

5 J.J. Thomson conducted experiments with a beam of cathode rays. By studying the effect of electric and magnetic fields on

these rays, he concluded that the rays consisted of negatively charged particles.

Let us now consider a composite atom made of protons and electrons. A proton is positively charged and is 1838 times heavier or more massive than the electron which is negatively charged. The next question is—how are these particles distributed within the atom? We could, of course, suppose that they are uniformly distributed, and that the entire atom looks like a water-melon (*tarbooz*) or a custard apple (*sharifa*).

However, an experiment conducted by Rutherford caused one more surprise. Rutherford took a thin gold foil and made α-particles fall on it If our picture of a uniformly packed atom is correct, we would expect the particles to be bent only slightly. We would also expect all the particles to be deflected to more or less

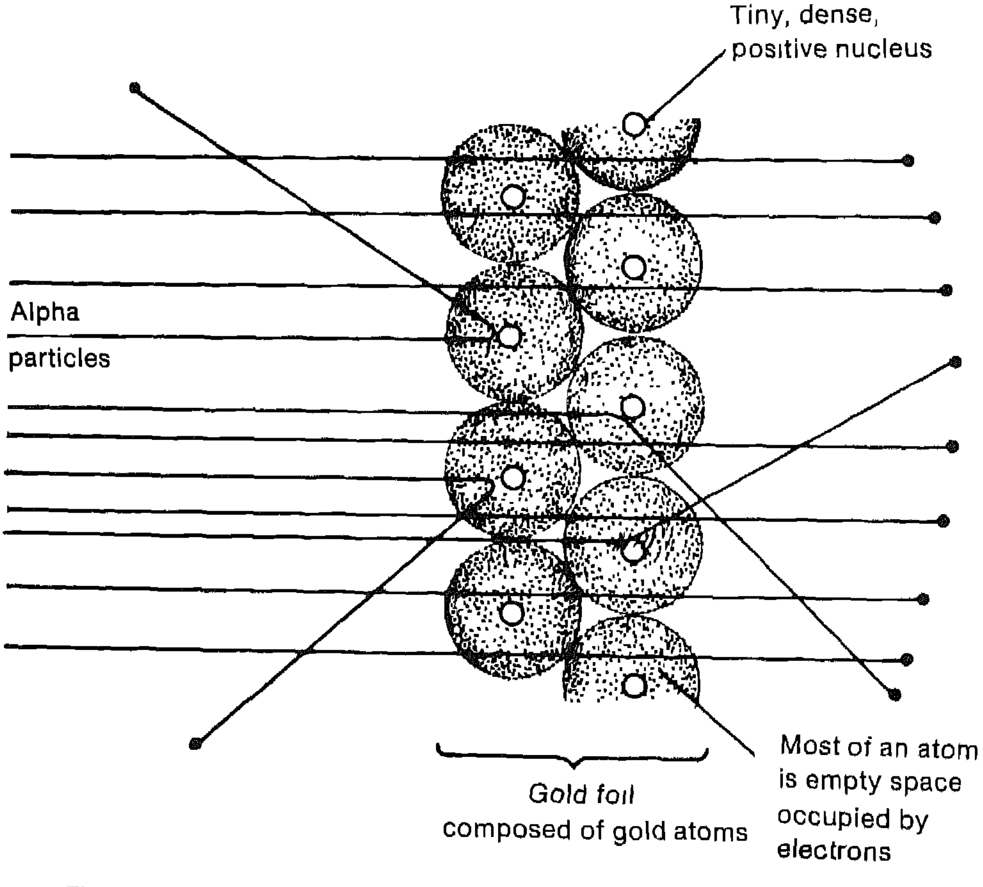

Tiny, dense, positive nucleus
Alpha particles
Gold foil composed of gold atoms
Most of an atom is empty space occupied by electrons

Fig 1.3 *Rutherford's experiment Alpha particles are scattered by a thin gold sheet. Most of the particles pass through but a few bounce back, after hitting the nucleus*

the same extent. What Rutherford found was amazing. He found that most of the particles went straight through the gold foil However, a few, a very few, in fact about 1 in 100,000 were deflected to a large extent It appeared as though these particles were indeed bouncing back (Fig 1.3) Why should only very few particles bounce back?

> He said, "It was quite the most incredible event that has ever happened to me in my life It was almost as incredible as if you fired a 15 inch shell at a piece of tissue and it comes back and hits you."

Rutherford suspected that the atom of gold might have a tiny heavy nucleus of protons in the centre surrounded by electrons. Only the particles hitting this nucleus would bounce back, while all the others would pass through Rutherford did not stop at this stage The gold foil that he used was about 0.4 micrometre (0.0004 mm) thick, which meant that the particle would have to pass through 1000 layers of gold atoms. He repeated the experiment using a gold film twice as thick and found that the number of particles bouncing back doubled He then used the simple rule of three If the film is 1000 layers thick, one particle in 100,000 (or 10^5) is bounced back With just a single layer, only one in 10^8 would be bounced back

These numbers mean that the area presented by the nucleus must be 10^{8} smaller than the total area presented by the atom as a whole That is, the nucleus must be very small, compared to the size of the atom

We now know the nature of the atom It has a very small nucleus which contains heavy particles like protons while the tiny electrons go round this nucleus

> Let us make a scale model The diameter of the nucleus is 10^{-15} cm, the diameter of the atom is about 10^{-8} cm Let us take 10^{-8} cm as 1 cm, and blow up this atom The nucleus would be an average size green pea 1 cm across Where would the electrons be? The electron would be at a distance of 10^5 cm or 1 km! Now do you see how hollow an atom is? If you try to shoot at this atom using small balls as bullets, the balls would mostly go through. Only occasionally would one in 100,000 score a direct hit and be bounced back

How are the electrons arranged? Do they go round the nucleus in one circle, or does each one move in a separate circular orbit? These questions were answered by the Danish physicist Niels Bohr

The two elementary particles, the proton (p) and the electron (e) were discovered by 1910. Now how do we build an atom using these particles? We know that p is 1838 times heavier than e. So, if we put all protons in the nucleus and an equal number of electrons around it we should be able to describe all the atoms But there is a serious problem in this arrangement.

The hydrogen atom, the lightest of all atoms has one proton in the nucleus and one electron going round it Helium has two electrons and two protons However, it is four times heavier than hydrogen Look at Table 1 1

Table 1.1

ATOMIC NUMBERS AND MASSES OF SOME ELEMENTS

Element	*No. of Electrons*	*No of Protons*	*Weight in terms of hydrogen*
H	1	1	1
He	2	2	4
O	8	8	16
S	16	16	32
Hg (mercury)	80	80	200

Is this table correct? Why are the weights of these elements double or more than expected?

The first guess was that the nucleus contains twice the number of protons Then one had to assume that it also must have twice the number of electrons to make the atom electrically neutral From the data one would have to conclude that oxygen has 16 protons and 16 electrons, and of these 8 electrons are inside the nucleus and 8 outside There were several objections to this hypothesis Can you construct a model of an atom consistent with Table 1 1, and with only protons and electrons?

The problem was solved when another atomic constituent, a particle called the neutron, was discovered It was found that a neutron weighs nearly as much as a proton, but has no charge Thus, for example, an oxygen atom would have 8 protons, 8 neutrons (total mass = 16) and 8 electrons. Now everything fits so well. In heavier atoms, the number of neutrons is more than the number of protons For example, mercury (Hg) has 80 protons and 120 neutrons

The mass of an atom is the combined masses of its protons and neutrons For mercury, the **atomic mass** is 80 + 120 = 200 atomic mass units (a.m u). But the **atomic number** of an atom is simply the number of protons it has The atomic number of mercury (Hg) is 80 The atomic number is simply a number.

Let us now come back to the question of how electrons are arranged around the nucleus It is now known that

1. Electrons move around the nucleus in **shells** or **orbits** - just as planets move around the sun.
2. The first, or the innermost shell can take only two electrons.
3. The second shell can contain up to 8 electrons.
4. The next shell can also take up to 8 electrons
5. Beyond this, shells become rather big, and have smaller shells within called '**sub-shells**. Two subsequent shells can accommodate as many as 18 electrons.
6. Normally, electrons are not

accommodated in a given shell unless the earlier shells are filled—that is, a stepwise filling of shells is followed

Using these rules, we can start building up an atomic table A short notation for the arrangement is given in the last column (Table 1 2)

Table 1 2

ELECTRON DISTRIBUTION IN SOME ATOMS

Element	*Number of Electrons*	*Arrangement of Electrons in Shells*	*Electron Distribution (notation)*
Hydrogen (H)	1	1 electron in 1st shell	1
Helium (He)	2	2 in 1st shell (full)	2
Lithium (Li)	3	1st shell full + 1 in 2nd shell	2,1
Berylium (Be)	4	1st shell full + 2 in 2nd shell	2,2
Boron (B)	5	1st shell full + 3 in 2nd shell	2,3
Carbon (C)	6	1st shell full + 4 in 2nd shell	2,4
Nitrogen (N)	7	1st shell full + 5 in 2nd shell	2,5
Oxygen (O)	8	1st shell full + 6 in 2nd shell	2,6
Fluorine (F)	9	1st shell full + 7 in 2nd shell	2,7
Neon (Ne)	10	1st shell full + 8 in 2nd shell (full)	2,8
Sodium (Na)	11	1st and 2nd shells full + 1 in 3rd shell	2,8,1
Magnesium (Mg)	12	1st and 2nd shells full + 2 in 3rd shell	2,8,2
Aluminium (Al)	13	1st and 2nd shells full + 3 in 3rd shell	2,8,3
Silicon (Si)	14	1st and 2nd shells full + 4 in 3rd shell	2,8,4
Phosphorus (P)	15	1st and 2nd shells full + 5 in 3rd shell	2,8,5
Sulphur (S)	16	1st and 2nd shells full + 6 in 3rd shell	2,8,6
Chlorine (Cl)	17	1st and 2nd shells full + 7 in 3rd shell	2,8,7
Argon (Ar)	18	1st and 2nd shells full + 8 in 3rd shell (full)	2,8,8

Table 1.2 also shows an interesting property of atoms **When a shell is full, the atom is chemically inert.** For example, helium has its first shell full Neon has its first and second shells full Argon has a closed shell arrangement of electrons too. Helium, neon and argon are all chemically inert or unreactive An important rule of chemical reactivity emerges The **chemical properties of atoms can, in fact, be explained from the way electrons are arranged in them.**

1 3 Radioactivity

We mentioned earlier that some substances are radioactive, that is, they emit spontaneously some charged particles like α-rays or β-rays or emit radiation (gamma rays). Why is it that certain atoms are radioactive while many others are not?

If you look at the table of elements carefully, you will notice that as you move towards the heavier atoms you find the number of neutrons exceeds the number of protons in the atom If the nucleus of an atom has too many neutrons it becomes unstable Let us take a simple example to illustrate this point

Normally a carbon atom has six protons and six neutrons in the nucleus, and six electrons in the shells. Consider a carbon atom with 6 *protons*, 8 *neutrons* and of course six electrons The nucleus of this atom is rather unstable If one of the neutrons can change into a proton, we would have a nucleus with 7 protons and 7 neutrons—which is in fact a nitrogen nucleus However, the total charge has to be conserved and the atom must be electrically neutral. So the following reaction takes place.

$$^{14}C_6 \longrightarrow {}^{14}N_7 + e$$

$$(n \longrightarrow p + e)$$

$$^{14}N_7 + e^- \longrightarrow {}^{14}N_7$$

or essentially $n \longrightarrow p^+ + e^-$

The resulting nitrogen is stable and does not emit any radiation But you will have noticed that the resulting atom is not quite nitrogen yet It has the nucleus of nitrogen, but its electronic structure resembles that of carbon An isolated $^{14}C_6$ (can you interpret these numbers now?) decaying into $^{14}N_7$ will remain positively charged. Otherwise it will pick up one electron from the surroundings and become uncharged nitrogen Where will this new electron go? Naturally it will be the 5th electron in the 2nd shell.

$^{14}C_6$ is a variety of carbon. Its chemical properties are exactly the same as normal carbon since its electronic configuration (arrangement) is the same as that of $^{12}C_6$ Such varieties are called isotopes. Isotopes of an atom have the same atomic number but have different atomic masses The number of protons in all isotopes of an atom is the same. Isotopes of an atom differ in the number of neutrons that they have Any two isotopes have the same number of electrons. Several atoms have isotopes. Not all isotopes are radioactive; only some are radioactive.

$^{14}C_6$ is produced on earth, probably by cosmic rays coming from interstellar space bombarding the earth's atmosphere. Since $^{14}C_6$ and $^{12}C_6$ have the same properties, the two isotopes get mixed together. Living organisms use CO_2. A small part of it has radioactive carbon. As long as the organism is living, it exchanges CO_2 with the surroundings. Hence the percentage of radioactive carbon remains constant. As soon as the organism (say a tree) dies the exchange ceases.

However, $^{14}C_6$ in the tree continues to decay, after 5800 years it will have only half as much $^{14}C_6$ as a living tree. In other words, by knowing the ratio of $^{14}C_6$ and $^{12}C_6$ in this tree, we can estimate how long the tree has been dead. For example, if we find only 25% as much $^{14}C_6$ as in a living sample, it must have died 5800 × 2 or 11,600 years ago. This method of estimating the age is known as **radio-isotope dating.** It is used extensively for dating archaeological samples.

QUESTIONS

1. Can you explain how the laws of constant proportions and multiple proportions lead to the idea of atoms?
2. Atomic masses are expressed in relative units, as a m u , with respect to ^{1}H as 1 a m u or ^{12}C as 12 a m.u We may also express the mass of an atom in absolute terms in grams An atom of neon has a mass of 3 35 X 10^{-23}g How many atoms of neon are there in 20 grams of the gas?
3. It is possible to write down the electronic configuration of an atom if we know its atomic number Why is this so?
4. When a neutral atom loses an electron or gains one, it becomes electrically charged, positively in the first case and negatively in the latter The atom is said to have formed a positive ion or a negative ion, respectively. What would be the electronic configuration of a positively charged sodium ion, Na^{+}? What would be its atomic number? What is its atomic mass?
5. Which of the two would be chemically more reactive, element X of atomic number 18 or element Z of atomic number 16?
6. The combining capacity of an element is called its valency The valency of hydrogen is 1, of magnesium 2, aluminium 3 and carbon 4 Can you see any connection between the valency of an element and the number of electrons it has in its outermost electron shell? What do you predict the valencies of helium (He), phosphorus (P) sulphur (S) and neon (Ne) to be?
7. Describe the principle of radio-isotope dating

CHAPTER 2

HOW ELEMENTS ARE CLASSIFIED

INTRODUCTION

OVER ONE hundred elements are known today Most of them take part in a variety of chemical reactions Thus, the total number of chemical substances in the world must be many millions Yet all these have to be made, using the hundred-odd elements as building blocks One would, therefore, need to understand the rules and the patterns of how these elements react and the basis of their properties If we did not have such rules and patterns, understanding the elements would be very difficult. It would be somewhat like having hundreds of students together in a school and not knowing which ones are in which class

Even untill about 120 years ago, scientists were trying to classify and group elements based on their properties Lithium (Li), sodium (Na) and potassium (K) were grouped in a family called the **alkali metal family**. They are all metals, they react readily with water and produce caustic solution called alkalies They all have a valency of one Fluorine (F), chlorine (Cl), bromine (Br) and iodine (I) were grouped in another family called the **halogens** with very similar properties They are very reactive non-metals, are monovalent and produce acids upon reacting with water Commonly known salts contain these elements—which is why they are called halogens (in Greek *halo* means salt, and *gen* generate). The elements magnesium (Mg), calcium (Ca), strontium (Sr) and barium (Ba) with their similar properties, were grouped in a family—the **alkaline earth family**. Yet, out of the 63 elements known at that time, no simple basis or property emerged on which all these elements with differing properties could be classified

2.1 Mendeleefs Periodic Law

Mendeleef was a Russian chemistry teacher who was working on the problem of classifying elements. He felt that there should be some order underlying the properties of all the elements known at the time. This order should be based on a fundamental property of the atoms of the element that would help in grouping them, understanding their reactions and also in predicting the properties of an element. Truly this is the idea in science—to systematise, understand and to predict He argued that a successful classification should be simple, elegant, widely applicable and based on a single and unique parameter. The important point was—on what basis should one classify? One earlier attempt classified sodium and lead together as belonging to the group of metals. But this is the only common property that sodium and lead share—they are otherwise very different. Thus classifying elements as metals and non-metals is inadequate. What is needed is a fundamental quantity or criterion out of which most of the properties of the atoms could be easily understood, explained and predicted.

Mendeleef took 63 cards and wrote on them the names and properties of the elements. He then examined all the facts known about them, sorted out the elements with similar properties and pinned their cards together on the wall. His card pattern or table looked somewhat like Figure 2.1.

When the elements were arranged in the order of increasing atomic weights, 7 groups emerged. The elements in each group were similar to one another in not a few, but in many properties. The properties repeated periodically, that is, after every seventh element. Arrangement on this basis was clearly better than arrangements based on metallic property, density or any other property. Here was a law he could state based on this trend. That is, the properties of elements are periodic functions of their atomic weights. This is the periodic law of Mendeleef. Now, he did a remarkable thing with the element titanium (Ti). Rather than place it under aluminium (Al) he put it under silicon (Si) based on their similar properties. This left a gap below aluminium (Al). If the periodic law is right, it would mean that the gap should be filled by a yet-to-

Groups:	I		II		III		IV		V		VI		VII		VIII
General formulas:	R_2O RCl		RO RCl_2		R_2O_3 RCl_3		RH_4 RO_2		RH_3 R_2O_5		RH_2 RO_3		RH R_2O_7		RO_4
Family.	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
1		H													
2	Li		Ba		B		C		N		O		F		
3		Na		Mg		Al		Si		P		S		Cl	
4	K		Ca				Ti		V		Cr		Mn		Fe, Co.Ni
5		Cu		Zn						As		Se		Br	
6	Rb		Sr		Yt?		Zr		Nb		Mo				Ru,Rh, Pd
7		Ag		Cd		In		Sn		Sb		Te		I	
8	Cs		Ba		Di?		Ce?								
9															
10					Er?		La?		Ta		W				Os Ir Pt
11		Au		Hg		Tl		Pb		Bi					
12							Th				U				

Fig. 2.1 *Mendeleef's periodic table. 63 elements were known at that time.*

be discovered element. Also, this element should have an atomic weight below 48 and properties similar to boron (B) and aluminium. This prediction of Mendeleef, based on the periodic law, was verified within five years by the discovery of the element gallium (Ga).

2.2 Atomic Property is the Basis

There were several remarkable things about Mendeleefs periodic law

1. It grouped elements on a more fundamental basis than earlier attempts did
2. It could predict the properties of several elements, based on their positions in the periodic table, e.g. scandium (Sc), gallium (Ga) and germanium (Ge)
3. It could predict errors in the atomic weights of elements based on their position in the table, e.g. gold (Au) and platinum (Pt).
4. Not one single feature of the table went wrong. Even when a whole class of new elements, the inert gases was discovered, it found a place in the Table, essentially as a fresh group without upsetting the existing order Mendeleef had to accommodate 63 elements known at his time. Yet the table that he made had a proper and reserved seat for each one of the elements that were discovered later, without disturbing the old order.

Mendeleefs idea was brilliant because it insisted on a fundamental and atomic property as the basis. In the classification of known elements, he was guided by two factors: (i) grouping of similar elements, and (ii) increasing atomic weight This actually led him to use the nature of atomic weights known then as the only guide number. They were not immutable constraints to his attempted arrangement. Remember what he did with Titanium? It is important because he used them in spite of the fact that atomic weights do not vary from one atom to the next in a fixed or uniform way.

2.3 Modern Periodic Table

Mendeleef attempted to classify elements not on their properties alone, but to seek a fundamental basis that would predict many properties of a given element. His genius lay in looking for an atomic basis and not giving up because the only atomic property he knew, the atomic weights, did not help him totally in this quest

Fig 2 2 shows the modern version of the periodic table including all the 107 elements that we know Compare it with Mendeleefs Figure 2 1, and you will find that the elements he classified are still in the same place. You will also find that the atomic number increases by one from element to element. The confusion or irregularity in the atomic weight increase is resolved.

The properties of elements are periodic functions of their atomic number. We can also appreciate how close Mendeleef was to arriving at this modern periodic law, atomic number was the quantity that he was looking for as the basis. Unfortunately, it was not known in his time. The atom was then

PERIODIC CLASSIFICATION
OF THE ELEMENTS
(BASED ON $C^{12} = 12\ 0000$)
1961 ATOMIC WEIGHTS

Light Metals		Heavy Metals										Nonmetals					
IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII B			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H 1 0080																	2 He 4 003
3 Li 6 939	4 Be 9 012											5 B 10 81	6 C 12 011	7 N 14 007	8 O 15 9994	9 F 18 998	10 Ne 20 183
11 Na 22 990	12 Mg 24 31											13 Al 26 98	14 Si 28 09	15 P 30 974	16 S 32 064	17 Cl 35 453	18 Ar 39 948
19 K 39 102	20 Ca 40 08	21 Sc 44 96	22 Ti 47 90	23 V 50 94	24 Cr 52 00	25 Mn 54 94	26 Fe 55 85	27 Co 58 93	28 Ni 58 71	29 Cu 63 54	30 Zn 65 37	31 Ga 69 72	32 Ge 72 59	33 As 74 92	34 Se 78 96	35 Br 79 909	36 Kr 83 80
37 Rb 85 47	38 Sr 87 62	39 Y 88 91	40 Zr 91 22	41 Nb 92 91	42 Mo 95 94	43 Tc (99)	44 Ru 101 1	45 Rh 102 90	46 Pd 106 4	47 Ag 107 870	48 Cd 112 40	49 In 114 82	50 Sn 118 69	51 Sb 121 75	52 Te 127 60	53 I 126 90	54 Xe 131 30
55 Cs 132 91	56 Ba 137 34	57 TO 71	72 Hf 178 49	73 Ta 180 95	74 W 183.85	75 Re 186 2	76 Os 190 2	77 Ir 192 2	78 Pt 195 09	79 Au 197,0	80 Hg 200 59	81 Tl 204,37	82 Pb 207 19	83 Bi 208 98	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226 05	89 TO 103															

Lanthanide series	57 La 138 91	58 Ce 140 12	59 Pr 140 91	60 Nd 144.24	61 Pm (147)	62 Sm 150 35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167 26	69 Tm 168 93	70 Yb 173.04	71 Lu 174 97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa (231)	92 U 238 03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (249)	98 Cf (251)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lw (257)

Fig. 2.2 *The long form of the periodic table*

considered indivisible

2.4 Electronic Configuration is the Basis

We can immediately see the basis of the periodic table of elements The table is arranged in 8 vertical columns—**groups** (groups I-VII and 0) and 7 horizontal rows—**periods.** The first period has only 2 elements, hydrogen and helium The second has 8 elements and so has the third period. The fourth and fifth periods have 18 elements each, while the sixth row is the largest with 32 elements including 14 metals of the rare earth family.

This progression of 2, 8, 8, 18, 18, 32 elements immediately suggests that these represent the electronic configurations of atoms of different elements. The atomic number is the number of protons and is also the number of electrons in each neutral atom. You saw in the last chapter that the first electronic shell can have 2 electrons, the second 8, and so on Let us write the electronic configuration of the elements of the first, second and third periods

Now we can see the logic of Mendeleefs arrangement based on an atomic property and how close he was to the

ELECTRONIC CONFIGURATION OF FIRST, SECOND AND THIRD PERIODS

Element	*Atomic No*	*Electronic Configuration*
H	1	1
He	2	2
Li	3	2, 1
Be	4	2, 2
B	5	2, 3
C	6	2, 4
N	7	2, 5
O	8	2, 6
F	9	2, 7
Ne	10	2, 8
Na	11	2, 8, 1
Mg	12	2, 8, 2
Al	13	2, 8, 3
Si	14	2, 8, 4
P	15	2, 8, 5
S	16	2, 8, 6
Cl	17	2, 8, 7
Ar	18	2, 8, 8

modern version of the periodic table.

Do you see why the first period has only two elements? The first shell can contain only two electrons. Hence there can be only two elements here, that of atomic numbers 1 and 2. Why does the second period have eight elements and not 7 or 9? And why do the elements of a given group have similar properties? To answer these questions, let us look at the periodic table (Figure 2.2) more closely.

2 5 Groups

The vertical columns called groups are numbered from 0 to VII. The 0 group is on the extreme right and group I is on the extreme left as in Figure 2.2. Elements in the same group have the same number of electrons, in the outermost shell, called valence electrons (see Question 1 of Chapter 1). **The chemical properties of an atom are largely governed by its valence electrons.** This is why atoms in a given group are similar in their properties. Take the atoms in group I. Their electronic configurations are as: H (1), Li (2, 1), Na (2, 8, 1) K (2, 8, 8, 1) and so on. These atoms can lose their single valence electron easily, when very little energy is supplied to them and become **ions** with a single positive charge. Thus in their chemical reactions group I elements are monovalent and ionic in nature. Similarly, the elements of group II have two electrons in their outermost shell. The atoms of group II can lose both their valence electrons with ease. They would also be ionic with two positive charges, and, therefore, divalent.

At the other end are the group VII elements, with their electronic arangement. F(2, 7), Cl (2, 8, 7), Br (2, 8, 18, 7) and so on. For these atoms, it is easier to capture an electron into their valence shells and complete it. This would transform the atoms into ions with a single negative charge. Chlorine (2, 8, 7) + electron → chloride ion (2, 8, 8). In their reactions, therefore, group VII elements are usually ionic and monovalent with a negative charge. Group 0 elements are the most inert and unreactive. Their configurations are as He (2), Ne(2, 8), Ar(2, 8, 8) and so on Their outermost shell is already completely filled. The atoms have no tendency to gain or lose electrons to complete the outermost shells. Thus the elements of group 0 are zero-valent and unreactive.

2.6 Periods or Rows

The horizontal rows of elements in the

periodic table are called **periods or rows** The elements hydrogen and helium form the first period. Lithium, berilium, boron, carbon, nitrogen, oxygen, fluorine and neon form the second period There are 7 periods or rows in all. The elements of the first period have one electron shell. Those of the second period have two shells of electron. As one moves in the same row from left to right, the valence electron shell gets progressively filled. For example, in the first period . H (1), He (2) In the second period we have Li (2, 1), Be (2, 2), B (2, 3), C (2, 4), N (2, 5), O (2, 6), F(2, 7) and Ne (2, 8). The atoms in the third row have three electron shells-Na (2, 8, 1) while those in the fourth row have four shells Ca (2, 8, 8, 2) and so on.

In a given period, the outermost or the valence shell gets progressively filled from group I to group 0. In a given group, on the other hand, the number of electron shells, increases but the number of electrons in the outermost shell is the same. The place of an element in the table thus defines its electronic configuration and therefore, its chemical properties.

How do the properties of elements progress or change in a period? The elements in the extreme left (group I, II) are metals and, as we come to the centre of the row(group IV), we encounter non-metals. We can see this better in Table 2.1.

Several interesting trends are seen in the properties of the third row elements.

Table 2.1

SOME PROPERTIES OF THE ELEMENTS OF PERIOD 3

Group	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*0*
Element	Na	Mg	Al	Si	P	S	Cl	Ar
Electron configuration	2,8,1	2,8,2	2,8,3	2,8,4	2,8,5	2,8,6	2,8,7	2,8,8
Atomic radius (in nm)	0.186	0.160	0.143	0.117	0.110	0.104	0.099	0.154
Nature of element	Metal	Metal	Metal	Non-metal	Non-metal	Non-metal	Non-metal	Non-metal
Nature of bonding	ionic	ionic	ionic, Covalent	Covalent	Covalent	Covalent, ionic	Covalent, ionic	—
Oxides	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_3 P_2O_5	SO_2 SO_3	Cl_2O_7 Cl_2O_6 ClO_2 Cl_2O	
Nature of the oxides	Basic	Basic	Basic-Acidic	Acidic Basic	Acidic	Acidic	Acidic	

You can now understand the reason behind this trend and perhaps answer the following questions after studying Table 2.1. Why does the size of the atom progressively become smaller (atomic radius decrease) from Na to Cl? Why is argon bigger in size than chlorine? Why is silicon tetravalent while cholrine is monovalent?

2.7 How to Predict Some Properties of an Atom

The position that an element occupies in the periodic table defines its electronic configuration. The electronic configuration of the element tells us how many shells of electrons it has. The group, the atom is in, tells us the number of electrons in its outermost shell or valence shell. This number defines many properties of the atom such as valency, metallic character, the size of the atom and so on. Thus, if you know the position of an atom in the table, you can predict its properties. For example, barium is an element of atomic number 56. Look up its position in the periodic table and answer the following: (a) Is it a metal or a non-metal? (b) Is it more reactive than calcium or less so? (c) What will be its valency? (d) What will be the formula of barium chloride? (e) Will it be larger than its neighbour cesium (Cs) or smaller?

QUESTIONS

1. Carbon (atomic number 6) and silicon (atomic number 14) are elements in the same group of the periodic table. Give the electronic arrangements of the carbon and silicon atoms, and state the group in which these elements occur.
2. For the main groups of the periodic table, the metallic properties of the elements vary approximately with their positions as shown in the chart below.

1	2	3	4	5	6	7	0
H							He
A						B	
C						D	

   (a) Where will you find the most metallic element?
   (b) Where will you find the most non-metallic element?
   (c) Where will you find the smallest atom?
3. In the periodic table given below lithium, carbon, oxygen and neon are placed in their correct positions. The positions of nine other elements are represented by

letters. These letters are not the symbols for the elements concerned By reference to the table, answer the following questions.

1	2	3	4	5	6	7	0
Lithium			Carbon		Oxygen	L	Neon
X			E		G	Q	
Y						R	
Z						T	

(a) Give the letter of the most reactive metal
(b) Give the letter of the most reactive non-metal
(c) *Name the family of elements represented by L, Q, R, T*
(d) Name one element in each case occuring in groups 2, 3, and 5

4 This question refers to the elments of the periodic table with atomic numbers from 3 to 18. Some of the elements are shown by letters, but the letters are not the usual symbols of the elements

3	4	5	6	7	8	9	10
A					E		G
11	12	13	14	15	16	17	18
B	C		D			F	

(a) Which of these
  (i) is a noble gas?
  (ii) is a halogen?
  (iii) is an alkali metal?
  (iv) is an element with valency 4?
(b) If A combines with F, what would be the formula of the resulting compound?
(c) What is the electronic arrangement of G?

5 Sodium and aluminium have atomic numbers of 11 and 13 respectively They are separated by one element in the periodic table, and have valencies of one and three respectively Chlorine and potassium are also separated by one element in the periodic table (their atomic numbers 17 and 19 respectively) and yet both have valency of one Explain the difference

6. Explain clearly why the atomic number of an element is more important to the chemist than its relative atomic mass number

7 Give symbols for
(a) a metal belonging to the second group of the periodic table
(b) a metal belonging to the third group of the periodic table.
(c) two non-metals belonging to the halogen family
(d) the most active halogen

8 Magnesium forms the following compounds

Magnesium oxide — MgO

Magnesium hydroxide – $Mg(OH)_2$

Magnesium sulphate – $MgSO_4$, If radium too belongs to the same group as magnesium, what would be the formulae of radium oxide, radium hydroxide and radium sulphate?

9 Write electronic structures of atoms of (i) potassium (ii) lithium (iii) fluorine (iv) chlorine Use these electronic structures to explain why potassium is more reactive than lithium, and fluorine more reactive than chlorine

10 Name two other elements which are in the same family as (i) carbon, (ii) fluorine, and (iii) sodium

CHAPTER 3

CHEMICAL BONDING

INTRODUCTION

ONE ATOM differs from another in its atomic number and electronic configuration. The properties of atoms are reflections of their electronic structures. Some atoms are more reactive than others. The elements in group 0 do not easily react and form compounds. Hence they are called inert gases. Earlier, they used to be called noble gases, as if it were a sign of nobility to be inert. We will look at the reason for this stability of the inert gases as well as the reactions of the not-so-noble elements in this Chapter.

3.1 Inert Gas Configuration is Stable

Look at the electronic configurations of the fluorine, neon and sodium atoms. Out of these, only Ne has the totally closed shell (completed shell) configuration. We saw in Chapter 1 that the distribution of electrons in the fluorine, neon and sodium atoms are

F (2, 7), Ne (2, 8), Na (2, 8, 1)

2 electrons in the first and 8 in the second shell is a stable and low energy state. That would mean that out of the three atoms Ne is the most unreactive and inert. Fluorine would become stable and inert if it could pick up an electron and complete its valence or outermost shell. Sodium would become stable if it could lose an electron and attain the cofiguration of neon (2, 8). Every atom has the tendency to acquire the configuration of the nearest noble gas and become stable.

What happens when the fluorine atom does so? Having picked up an electron, the atom has become the negatively charged **fluoride** ion. This negative charge will electrically attract a positive ion, and repel a negative ion. And what happens when the sodium atom attains closed shell stability by losing an electron? It becomes the singly charged positive ion Na^+. The sodium ion will now electrically attract a negative charge like Cl^- or F^-.

The electronic configuration of the calcium atom is (2, 8, 8, 2)—What would be the stable configuration for the Ca atom: the doubly charged Ca^{++} or the single charged Ca^+? Clearly Ca^{++}, since it is here that the inert gas argon configuration is reached, Ca^+ still has one electron in its outermost shell as potassium does. Similarly, O^{--} is a more desirable configuration than O^- or O for oxygen atom.

3.2 Ions, Atoms and Valency

The properties of Na^+ ion would be quite different from those of sodium atoms. The positive charge dictates all the properties of Na^+, since otherwise it is as stable and inert as the inert element neon, with its eight electrons (called octet) in the valence shell. A sodium atom, on the other hand, would strive to lose its lone valence shell electron This is what makes the Na atom and, indeed, all the group I alkali metal atoms chemically reactive The elements of group I, the alkali metals, have the tendency to lose the electron present in the outermost shell and to acquire the electron configuration of the noble gas

Na	$\longrightarrow$	$Na^+ + e^-$ (electron)
atom		ion
neutral but reactive		stable (neon configuration)
(2, 8, 1)		(2, 8) but charged, so electrically active

Similarly, the ionisation of chlorine atoms is as

$Cl + e^- \longrightarrow$	Cl^-
atom	ion
neutral but reactive	stable
(2, 8, 7)	(2, 8, 8) (argon configuration but charged, so electrically active)

The properties of Cl^- ions would be quite different from those of Cl atom

What happens when an atom of Na is brought close to a Cl atom? Each atom would like to attain the octet electronic configuration of the nearest noble gas. They can achieve this by transferring an electron from Na to the Cl atom as $Na + Cl \longrightarrow Na^+ + Cl^-$ to form the two electrically charged ions Being oppositely charged, they will attract and hold on to each other The result is a reaction that has produced the ion pair $Na^+ Cl^-$, which is what common salt is—sodium chloride. The two ions are **bonded together** by their electrical charges Such a bond is called the **ionic bond.** In making this bond, one electron has been lost from Na and one electron gained by Cl. The valency of sodium and of chlorine are one each, or they are monovalent The valency of an atom is the number of electrons it loses or gains (or shares) in making a bond with another atom. Look at the following examples.

Ca	$\longrightarrow$	$Ca^{++} + 2e$
(2, 8, 8, 2)		(2, 8, 8) stable (argon configuration)

Al	$\longrightarrow$	$Al^{+++} + 3e^-$
(2, 8, 3)		(2, 8,) (neon configuration)

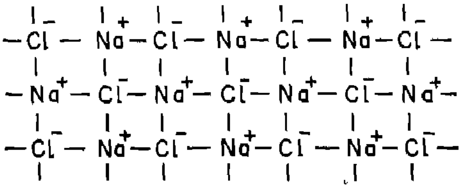
$O + 2e^-$	$\longrightarrow$	O
(2, 6)		(2, 8) stable (neon configuration)

What are the valencies of Ca, Al, and O? 2,3 and 2 respectively. Calcium chloride, aluminium chloride and aluminium oxide are ionic compounds. What would be their formulae? If we recall that chlorine has a valency of one, we can immediately write the formula as $CaCl_2$, $AlCl_3$ and Al_2O_3, respectively. You can now see how the laws of constant proportions and multiple proportions are hidden in the fromulae.

In having made the ion, the properties of the original atom are lost. Atomic sodium is a metal that easily reacts with oxygen in air to form Na_2O and reacts vigorously with water The ion Na^+ is inert, does not react with air or water and is only interested in attracting negative charges. The reactivity of Na atom is because of its tendency to attain a closed valence shell configuration Na^+, having attained it, is inert and all its properties are based on its single positive charge. This is why it is safe to eat Na^+Cl^-, common salt But you would not want to handle the elements sodium and chlorine.

3 3 NaCl is Actually $(Na^+Cl^-)_n$

Several properties of ionic compounds are interesting First, note that they are made up of pairs of opposite ions or electrically charged particles One Na^+ can and will attract as many negative charges as it can It does not have to be satisfied with one Cl^- Likewise, this Cl^- ion will attract several Na^+ Thus what we will have is not simply Na^+Cl^-, or an ion pair alone, but a regular arrangement of these ions in 3 dimensions. Such a regular arrangement is called a lattice (Fig 3 1)



—Cl — Na—Cl— Na—Cl — Na—Cl —
—Na⁺— Cl⁻— Na⁺— Cl⁻— Na⁺— Cl⁻— Na⁺—
—Cl⁻— Na⁺—Cl⁻— Na⁺— Cl⁻ —Na⁺— Cl⁻—

Fig 3.1 *The lattice of crystal of sodium chloride shown in two dimensions, the lattice is actually in three dimensions.*

The final material, the ionic compound, will of course have no net charge It will have an equal number of + and − charges or ions What is its formula? Na^+Cl^- or $(Na^+)_{100}(Cl^-)_{100}$ or $[(Na^+)_n(Cl)^-)_n$? It would have to be an extended lattice in three dimensions. That is why NaCl and other ionic compounds are crystalline solids with high melting points, high density and with all the ions placed symmetrically This is also why they generally dissolve in water Water weakens the force that holds the lattice intact, interacts with the individual ions and disperses them

The bond formed between the two ions Na^+ and Cl^- is one of electrical attractions between opposite charges For this reason, the ionic bond is also called **electrovalent**. Which are the best atoms that can be electrovalently bonded? Clearly, one of the atoms should readily lose electron so that it completes its octet electronic configuration and becomes positive ion. This atom is thus an **electropositive** atom, as most metals are Electropositive atoms tend to lose electrons and form positive ions

The other atom should then be **electronegative** as the halogens are, and do the opposite It should attract an electron to itself, achieve the closed shell configuration and become a negative ion. The two atoms thus complement each other well for ionic bonding

3 4 Sharing Electrons to Make a Bond

What about bonding between the two atoms that do not lose or gain electrons so easily? Electron transfer cannot happen so well then and the bonding will not be electrovalent. Let us take the example of the chlorine molecule Cl_2. Electron transfer is not possible since the atoms are not complementary but behave identically. Yet, each atom would like to attain the stable octet configuration by gaining one electron. They can resort to another method, and that is of **sharing electrons** as shown in Figure 3.2. Only these electrons which are in the outermost shell of the atom take part in bond formation. Therefore, it is only these electrons which are shown in the figure.

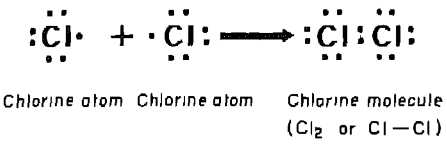


Fig 3.2 *Covalent bond—Single bond*

When the atoms of chlorine come close enough to one another each one can share its 7th electrons with the other. Upon doing so, each atom achieves its nearest noble gas configuration through sharing. The bonding between the two atoms is through their mutual cooperation by sharing a pair of electrons between them equally. Such a bond is called the **covalent** bond. Covalently bonded molecules do not usually conduct electricity.

In a covalent bond, both atoms attract the same pair of electrons. This shared pair is called the **bonding pair** of electrons; they act as the cement or the glue that holds the atoms together in the bond. One pair of bonding electrons makes one covalent bond. Thus we have a single bond between the two atoms in the chlorine molecule. What is the valency of the atoms here? The valency of an atom is then defined as **the number of electrons it loses, or gains, or shares** in bonding with other atoms in a molecule. This definition of valency includes both ionic and covalent bonding. The valency of chlorine in Cl_2 is one, just as it is in NaCl.

The same principle of equal sharing of electrons operates when an oxygen molecule is formed from O atoms. Each oxygen atom needs 2 electrons to complete its octet since its configuration is (2,6). Sharing with another atom occurs twice, as in Figure 3.3 and we have two covalent bonds joining the two oxygen atoms. There is a double bond in the oxygen molecule. Each oxygen has a valency of two, or is divalent.

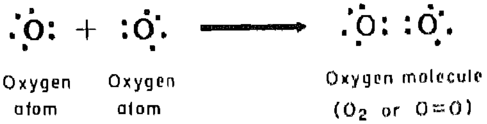


Fig 3.3 *Covalent bond—Double bond*

Triple bonds are formed similarly, by sharing three pairs of electrons between two atoms. N_2 is an example (Figure 3.4).

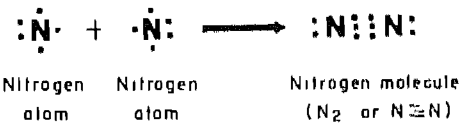


Fig. 3.4 *Covalent bond—Triple bond*

Let us look at the water molecule, H_2O. The two hydrogen atoms have only one electron each in their shells. Stability and inertness for the H atom would result if it gathers one more electron and completes its shell. Then it takes on the closed shell **doublet** configuration of the inert gas helium (remember H and He of atomic numbers 1 and 2 have just one electron shell). The oxygen atom with its 2, 6 configuration needs two electrons to

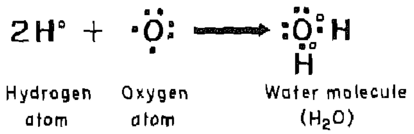


Fig 3.5 *Covalent bond between oxygen and hydrogen to produce the bonds in water*

complete its octet. The oxygen can share its electrons with two hydrogen atoms, or make two covalent bonds (Figure 3.5). The oxygen atom is divalent and the hydrogen atom monovalent, as before

3.5 Molecules Come in Various Shapes

Water provides an excellent example to point out some other interesting features of the covalent bond. Notice above that we wrote the molecule as H_2O and not as H-O-H in a straight line. **Covalent bonds are directional, or have definite geometry about them.** This is not so of ionic bonds, which represent charge attractions that are equally strong in all directions. In water, the two bonds are 105° apart. The same is true of ammonia, NH_3 where the trivalent nitrogen is covalently bonded to three H atoms, and of methane or CH_4 with its tetravalent carbon (Figure 3.6.).

Covalent bonds give molecules definite shapes. For example, ammonia and methane are tetrahedral shaped The ethylene molecule is planar, $Cu(NH_3)_4$ is square planar in shape, SF_6 is octahedral and so on (Figure 3.7a, 3.7b)

The carbon atom usually makes only covalent bonds with other atoms With its valency of 4, it can make a chain of bonds with more carbon atoms, leading to long thread-like molecules of large molecular weight Polythene or polyethylene is one such example, which resembles a long necklace of thousands of ... CH_2-CH_2-CH_2-CH_2 CH_2 groups (each a tetrahedron) strung together by covalent C-C bonds. Such molecules are called **polymers.** Polymers are tough, strong and fibrous. This structure and property enables us to make sheets and fabric out of polythene The plastic bag in which dairy milk is sold in many towns in made of polythene Light weight, yet strong, waterproof and convenient, thanks to the covalent bond. Other important polymers are nylon, polyester, polyvinyl chloride or neoprene (synthetic rubber).

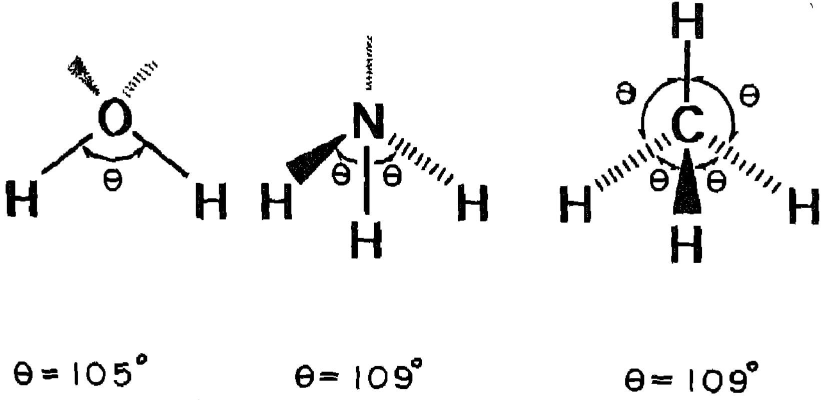
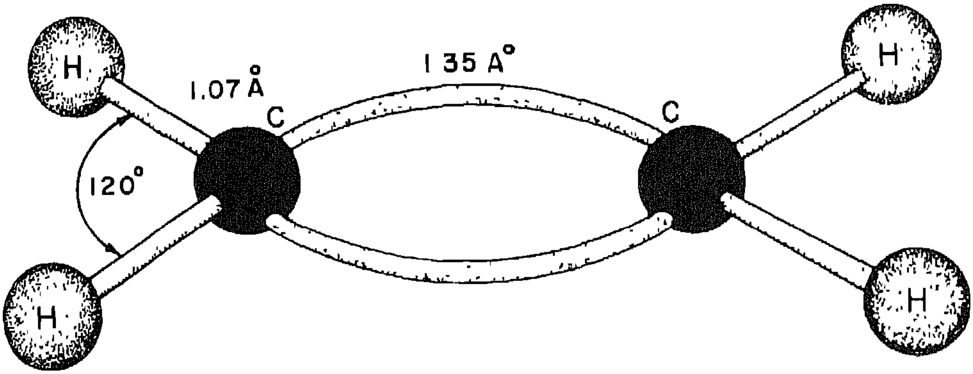
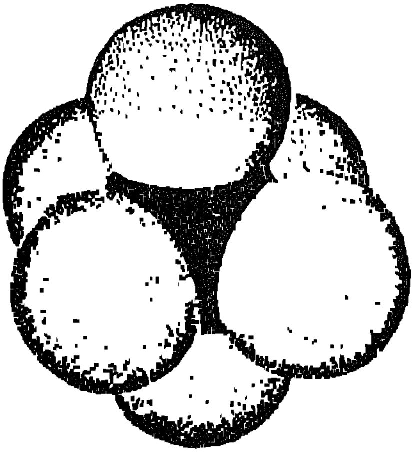


Fig. 3.6 *Covalent bonds offer definite geometries to molecules Ammonia and Methane are tetrahedral while water molecule is a distorted tetrahedron*

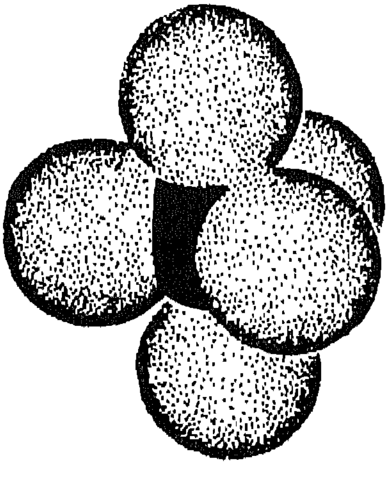


Ethylene C_2H_4

Ethylene molecule
(planar)

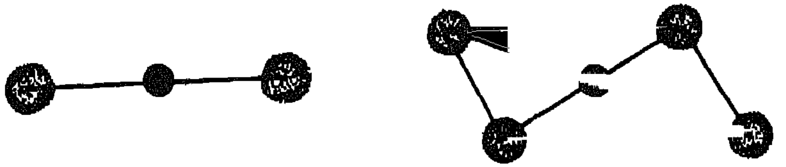


SF_6
Sulphur hexafluoride
(octahedral)

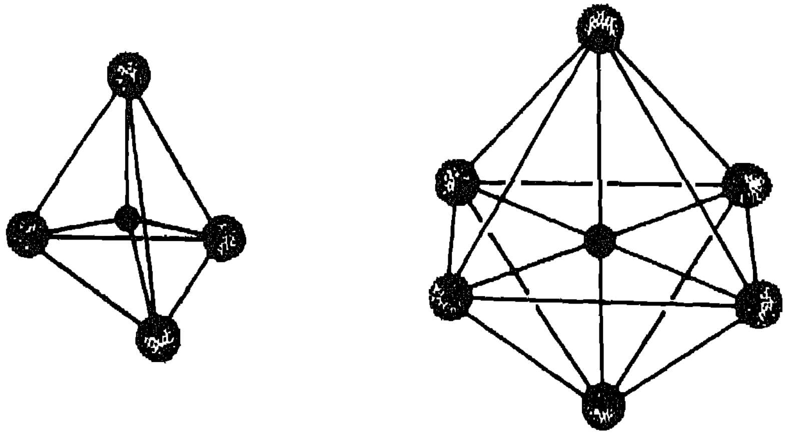


PCl_5
Phosphorus pentachloride
(Trigonal bipyramid)

Fig. 3.7



Linear (CO_2) Square-planar ($Cu(NH_3)_4$)



Tetrahedral (CCl_4) Octahedral (SF_6)

Fig. 3.7

3.6 Ionic and Covalent Compounds

The ionic bond and the covalent bond are the two modes by which atoms combine to form ionic lattices (NaCl) or molecules. The former involves charge attractions while the latter involves sharing electrons between bonded atoms. This difference is reflected in the properties of ionic and covalent compounds.

Ionic compounds can be dissociated into their constituent ions with little effort. Further, they can be electrolysed to produce elements or covalent molecules of the constituent atoms NaCl upon melting or upon dissolving in water, produces Na^+ and Cl^- ions Electrolysis of molten NaCl gives Na and Cl_2. Recall that electrolysis literally means breaking down, using electricity Water also weakens the attraction between the ions in an ionic compound This is why many ionic compounds dissolve well in water Organic liquids like benzene or kerosene cannot do so. NaCl is easily dissolved in water but not in kerosene or oil.

An ionic compound is literally a **collection of an equal number of positive and negative ions arranged in a three-dimensional lattice.** We saw how, because of this, the formula NaCl could be written as $Na^+_xCl^-_x$ where x is any positive integer. The lattice structure also leads to their being solids with high melting points. And, of course, ionic compounds can conduct electricity. Most ionic compounds are made of metals and the elements of group VII and VI.

In comparison, covalent compounds have quite different properties. They do not ionise or conduct electricity Electrolysis of covalent molecules is thus not possible. Many covalent compounds are not soluble in water. Covalent molecules dissolve much easier in organic liquids Since the bonding here is by electron sharing and not by electrical attraction, the number of atoms in covalent molecules is not indefinitely large They have lower melting and boiling points than ionic compounds. There are many covalent molecules that are in the gas phase or liquid state (Cl_2, H_2O) but there are very few ionic compounds that exist in the gas state at room temperature.

We thus see that the properties of a substance depend upon the arrangement of the atoms in the molecules of the substance. Ionic substances tend to be solids, often hard and often dissolve in water. They conduct electricity in the molten state or in a solution. Elements of groups I, II, and of VI and VII often constitute ionic compounds. This is because the former ionise to give positive ions while the latter can accept electrons to become negative ions Covalent compounds, on the other hand, are mainly made of elements of all groups, but particularly of the groups III to VII of the periodic table.

The same molecule can have both ionic and covalent bonds in it Sodium hydroxide (NaOH) and hydrogencyanide (HCN) are two easy examples. In NaOH, the hydroxide ion is made of a covalent bond between the O and H atoms, while in HCN the cyanide ion has a triple bond connecting the C and N atoms

$$Na^+(O\text{-}H)^- \quad H^+(C{\equiv}N)^-$$

Other examples are sulphuric acid (H_2SO_4), calcium carbonate ($CaCO_3$), potassium permanganate ($KMnO_4$) and ammonium nitrate (NH_4NO_3).

Atoms like Li and Na of group I, which lose their valence electron easily, form ionic bonds with ease Similarly, the atoms of the halogens of group VII pick up an electron easily to complete their valence shell octet configuration. These atoms also form ionic bonds. Alkali metals form positive ions while the halogens form halide ions of negative charge As we move towards the centre of the periodic table, the atoms of groups III-V do not ionise so easily and prefer to make covalent bonds. The carbon atom (of group IV) mainly makes bonds by sharing electrons with other atoms.

QUESTIONS

1 Fill in the blanks:

(a) Sodium atom can __________ one electron and attain the electronic structure of __________.

(b) Noble gases are stable because their outermost orbit contains __________ or __________ electrons

(c) Noble gases exist as individual __________

(d) When a chemical bond is formed between the atoms both the atoms acquire __________ configuration

(e) Chlorine atom can __________ one electron to become the chloride ion, whose electron configuration is similar to __________

(f) Oxygen atom can gain __________ electrons to form the oxide ion

(g) Two oxygen atoms form oxygen molecule by __________ two pairs of electrons

(h) Two nitrogen atoms form nitrogen molecule by sharing __________ pairs of electrons

(i) The chloride ion has a __________ charge.

(j) The sodium ion has a net __________ charge while the sodium atom has __________ charge

(k) The sodium ions and chloride ions together in a solid form a __________

(l) In an ionic bond, the ions are __________ together by __________ charged ions

(m) Ionic compounds are usually __________ in water.

(n) Ionic compounds are composed of __________ charged ions

(o) Covalent compounds have usually __________ melting point __________

(p) Covalent compounds are __________ of electricity.

(q) Covalent bonds are normally formed by __________ elements

2. Choose the right answer

(i) Sodium atoms and sodium ions
   - (a) are chemically the same
   - (b) have the same number of protons.
   - (c) have an identical number of electrons.
   - (d) form covalent bonds
   - (e) react spontaneously to water.

(ii) When sodium reacts with chlorine
   - (a) each sodium atom gains one electron
   - (b) each chlorine atom loses one electron
   - (c) a covalent bond is formed
   - (d) the compound formed is a solid
   - (e) the compound formed does not contain equal number of sodium and chloride ions

(iii) An ionic bond is formed when
   - (a) the combining atoms gain electrons
   - (b) the combining atoms lose electrons.
   - (c) a metallic element reacts with a non-metallic element.
   - (d) two metallic elements react.
   - (e) a pair of electrons is shared

3 Write down the formula of the compound resulting from the combination of an element X of atomic number 20 with the element Y of atomic number 17

4. (a) How many covalent bonds does an ammonia molecule have?
   (b) Why is it incorrect to talk of molecules of sodium chloride, but correct to talk of molecules of ammonia?

5 What are the bond types present in each of the following substances?
   (i) Water
   (ii) Nitrogen
   (iii) Magnesium oxide
   (iv) Calcium chloride

6 (a) Describe the bond that holds 2 hydrogen atoms together in a hydrogen molecule, H_2
   (b) Two argon atoms will not form a covalent bond to give an agron molecule Ar_2, why?

7. (a) How many electrons does oxygen need to achieve the electronic structure of the neon atom?
   (b) Justify the formula of magnesium oxide, MgO.

8 The elements W, X, Y and Z have atomic numbers, respectively of seven, nine, ten and eleven Write the formula for the compound you would expect to form between the following pairs of elements and indicate the type of bonding present
   (a) W and X (b) X and X
   (c) W and Z (d) Y and Y

9 A metal X (atomic number 19) burns in chlorine to produce a white, solid chloride Y. By means of diagrams, illustrate the arrangement of electrons in X both before and after the reaction.

CHAPTER 4

CHEMICAL REACTIONS

INTRODUCTION

CHEMICAL REACTIONS involve the breaking of bonds and the making of new ones. Often energy needs to be supplied to get the reaction going. The energy supplied may be in the form of heat, light or mechanical shaking for proper contact between the reactant molecules or electricity. When chemical reactions occur, a great variety of rearrangement of atoms can take place

There are several examples of chemical reactions in daily life—the digestion of food, the curdling of milk, the ripening of fruit, fermentation of grapes to make wine or of rice flour and *dal* to make *idli* or *dhokla* and cooking Breathing itself leads to the reaction of molecules in our cells with the oxygen of the air There are, of course, a variety of chemical reactions, but all of them involve the breaking and making of bonds between atoms Thus chemical reactions produce new substances

4.1 Different Types of Chemical Reactions

A simple rearrangement of the atoms occurs in the reaction:

$$\underset{\text{Ammonium cyanate}}{H_4N_2CO} \xrightarrow{\text{heat}} \underset{\text{Urea}}{H_4N_2CO}$$

The molecular formula is the same but the bonds are rearranged. Such compounds are called **isomers** of each other. The German chemist Wohler discovered this reaction and showed that organic chemicals can be made from other sources too, and that they do not need to come from living organisms only

A **decomposition reaction** occurs when a molecule is broken down into smaller parts Passing electric current through water produces H_2 and O_2. This electrolysis reaction (electro = electrical ; lysis = breakdown) is one example of a decomposition reaction

$$2H_2O \xrightarrow{\text{electricity}} 2H_2+O_2$$

Notice that decomposition is the opposite of a **combination reaction.** Water can be made by combining H_2 and O_2, simply by burning hydrogen gas in air. Another example of a combination reaction happens when we whitewash walls with lime. Lime (calcium oxide), when added to water, forms slaked lime (calcium hydroxide). Calcium hydroxide reacts slowly with the carbon dioxide in the air to form a thin layer of calcium carbonate on the walls.

$CaO + H_2O \rightarrow Ca(OH)_2$

Lime water slaked lime or lime water

Lime water + carbon dioxide → calcium carbonate limestone

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Activity 1

Take a beaker half-filled with water and drop a piece of limestone (calcium carbonate) into it. You will not see any reaction. Now take another piece of limestone, hold it with a pair of tongs and heat it over a flame for 5-10 minutes. After it has cooled, drop it in water and observe. The water will have warmed up.

Upon heating, the limestone first decomposes to produce CaO (calcium oxide or quicklime). CaO reacts with water vigorously to produce lime water (slaked lime). The energy released in this reaction comes out partly as heat, warming the water.

$$CaCO_3 \xrightarrow{heat} CaO + CO_2$$
$$CaO + H_2O \longrightarrow Ca(OH)_2 + heat$$

Activity 2

Take some ferrous sulphate crystals, $FeSO_4$, in a porcelain dish with the help of a spatula. You will notice that it is green in colour. Heat the dish over the flame of a spirit lamp. You will notice that the green colour has changed and also that you can smell the characteristic smell of sulphur burning. Heating decomposes $FeSO_4$ as per the reaction:

$$2\,FeSO_4 \xrightarrow{heat} Fe_2O_3 + SO_2 + SO_3$$

Ferric oxide, Fe_2O_3, is the solid product while SO_2 and SO_3 are the gaseous products which produce the smell.

Decomposition reactions are used in order to obtain several metals from their oxides or salts. The salt is electrolysed and the pure metal obtained. Digestion in the body is another example. When we eat potatoes, rice or wheat, the starch in these gets decomposed to simple sugar in the body and the proteins get decomposed into simpler substance called amino acids

A **displacement reaction** involves the displacement of one set of atoms in a molecule by another. In the next activity, we study the displacement of copper in a salt by another metal

Activity 3

Displacement of copper from copper sulphate ($CuSO_4$) by other metals such as Mg (magnesium), Zn (zinc) and Fe (iron).

Take three beakers, and fill each of them about half with copper sulphate solution. A solution of 5 g of the salt in 100 ml of water will do. The colour of the solution will be peacock-blue. Into the first beaker add about 5 g magnesium metal; into the second about the same amount of zinc metal and into the third iron nails likewise. Keep the beakers undisturbed for some time. Soon you will see the peaccok-blue colour of $CuSO_4$ fading, and a shiny coat of copper metal replacing it on the metal pieces that you added. With iron, a lighter green will replace the blue colour of the copper sulphate solution, while with the other two, the solution turns colourless. The displacement reactions are.

$$Mg + CuSO_4 \longrightarrow MgSO_4 + Cu$$
$$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$$
$$Fe + CuSO_4 \longrightarrow FeSO_4 + Cu$$

There are several other types of reactions. Oxidation involves reaction with oxygen, while reduction is the opposite, and is often a reaction with hydrogen. In the formation of water from its elements, oxygen is reduced while hydrogen is oxidised. And our first example, when ammonium cyanate was transformed into urea, illustrates an isomerisation reaction.

4 2 Chemical Formulae and Equations

We have been writing formulae and equations with molecules almost as algebraic expressions and equations. Indeed they are quite so, and they have precise meanings. Stop and think all that the formula H_2O represents.

(a) It means two atoms of hydrogen and one atom of oxygen are in one molecule of water.

(b) It shows that the valency of oxygen here is two, while that of hydrogen is one.

(c) It represents the molecular weight of H_2O to be 18, composed of 16 from one oxygen atom and 2 from the two hydrogen atoms.

(d) It indicates that the compound H_2O is not electrically charged. It is not ion but a neutral molecule. Like any other formula, a chemical formula is thus **a shorthand expression of many quantitative facts and ideas.** If we now look at the equation:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

We notice again that a chemical equation conveys a lot of rigorous information

(e) It is not written as $H_2 + O \rightarrow H_2O$. The O_2 shows that the reaction occurs with elemental oxygen or oxygen molecules, the (g) next to O_2 shows that the oxygen is in the gaseous form. (l) stands for liquid and (s) for the solid state

(f) We took elemental O_2 that contains two atoms of oxygen to react with elemental H_2. Each molecule of water formed has only one atom of oxygen. But then we do not produce free oxygen atoms. Hence we **balance** the equation so that the number of atoms on the left side of the equation is the same as on the right.

If we did not balance it we would be losing or creating atoms. This is why H_2 is shown as $2H_2$. Two molecules of hydrogen react with one molecule of oxygen to produce 2 molecules of water This balances the equation with respect to all atoms.

(g) The equation $2H + O \rightarrow H_2O$, and $H_2 + O \rightarrow H_2O$ are also balanced equations. They would be true, however, only if we had taken hydrogen atoms or oxygen atoms as reactants. This is possible under certain conditions when free atomic oxygen or hydrogen exists and is used. Generally, oxygen and hydrogen exist not as atoms but as molecules.

(h) The equation not only balances the number of atoms but also their masses. $2H_2$ means **four hydrogen atoms** of total mass 4 (in units of atomic mass, not units of grams or kg). O_2 means $2 \times 16 = 32$ a.m.u. **(atomic mass units).** The total mass on the left side is $4 + 32 = 36$ a m.u. The right hand side has two molecules of water. The mass of these is a total of $18 \times 2 = 36$. Thus, the chemical equation balances mass as well.

(i) What about energy balance? In this reaction, heat is given out or liberated. This is generally expressed separately. The heat liberated is about 286 kilojoules (kJ) for every mole of liquid H_2O formed. The actual heat liberated in the reaction is thus 572 kJ, since two moles of H_2O are formed.

Thus, we see the meaning behind chemical formuale and equations We will use and understand them in some detail in this chapter.

4.3 Atomic and Molecular Masses

We said that the atomic mass of hydrogen is 1 in units of atomic masses or a m.u. (atomic mass unit) The atomic mass of an element is the relative mass of one atom of the element compared with an atom of carbon as the standard.

The atomic mass of the standard, the isotope ^{12}C of carbon, is chosen to be 12 Hence 1 atom of hydrogen has 1/12 the mass of the standard ^{12}C Its atomic mass is 1 a m u. The atomic mass of oxygen is 16 a m u. Table 4.1 gives the atomic masses of all the elements and is a very useful table that you can use.

Table 4.1

INTERNATIONAL ATOMIC WEIGHTS

Element	*Symbol*	*Atomic Number*	*Atomic Weight*	*Element*	*Symbol*	*Atomic Number*	*Atomic Weight*
ACTINIUM	Ac	89	227	MERCURY	Hg	80	200 59
ALUMINUM	Al	13	26 98	MOLYBDENUM	Mo	42	95 94
AMERICIUM	Am	95	[243] *	NEODYMIUM	Nd	60	144 24
ANTIMONY	Sb	51	121 75	NEON	Ne	10	20 183
ARGON	Ar	18	39 948	NEPTUNIUM	Np	93	[237] *
ARSENIC	As	33	74 92	NICKEL	Ni	28	58 71
ASTATINE	At	85	[210]*	NIOBIUM	Nb	41	92.91
BARIUM	Ba	56	137 34	NITROGEN	N	7	14.007
BERKELIUM	Bk	97	[249]*	NOBELIUM	No	102	[254]*
BERYLLIUM	Be	4	9 012	OSMIUM	Os	76	190.2
BISMUTH	Bi	83	208 98	OXYGEN	O	8	15 994
BORON	B	5	10 81	PALLADIUM	Pd	46	106 4
BROMINE	BR	35	79 909	PHOSPHORUS	P	15	30 974
CADMIUM	Cd	48	112 40	PLATINUM	Pt	78	195 09
CALCIUM	Ca	20	40 08	PLUTONIUM	Pu	94	[242]*
CALIFORNIUM	Cf	98	[251]*	POLONIUM	Po	84	[210]*
CARBON	C	6	12 011	POTASSIUM	K	19	39 102
CERIUM	Ce	58	140 12	PRASODYMIUM	Pr	59	140 91
CESIUM	Cs	55	132 91	PROMETHIUM	Pm	61	[147]*
CHLORINE	Cl	17	35 453	PROTACTINUM	Pa	91	[231]*
CHROMIUM	Cr	24	52.00	RADIUM	Ra	88	226 05
COBALT	Co	27	58 93	RADON	Rn	86	[222]*
COPPER	Cu	29	63 54	RHENIUM	Re	75	186 21
CURIUM	Cm	96	[247]*	RHODIUM	Rh	45	102 90
DYSPROSIUM	Dy	66	162.50	RUBIDIUM	Rb	37	85.47
EINSTEINIUM	Es	99	[254]*	RUTHENIUM	Ru	44	101 10
ERBIUM	Er	68	167.26	SAMARIUM	Sm	62	150 35
EUROPIUM	Eu	63	151.96	SCANDIUM	Sc	21	44 96
FERMIUM	Fm	100	[253]*	SELENIUM	Se	34	78 96
FLUORINE	F	9	18.998	SILICON	Si	14	28 09
FRANCIUM	Fr	87	[223]*	SILVER	Ag	47	107 870
GADOLINIUM	Gd	64	157 25	SODIUM	Na	11	22.990
GALLIUM	Ga	31	69.72	STRONTIUM	Sr	38	87.62
GERMANIUM	Ge	32	72 59				

Element	*Symbol*	*Atomic Number*	*Atomic Weight*	*Element*	*Symbol*	*Atomic Number*	*Atomic Weight*
GOLD	Au	79	197 0	SULFUR	S	16	32.064
HAFNIUM	Hf	72	178 49	TANTALUM	Ta	73	180.95
HELIUM	He	2	4.003	TECHNETIUM	Tc	43	[99]*
HOLMIUM	Ho	67	164 93	TELLURIUM	Te	52	127.60
HYDROGEN	H	1	1 0080	TERBIUM	Tb	65	158.92
INDIUM	In	49	114 82	THALLIUM	Tl	81	204 37
IODINE	I	53	126 90	THORIUM	Th	90	232.04
IRIDIUM	Ir	77	192 2	THULIUM	Tm	69	168 93
IRON	Fe	26	55 85	TIN	Sn	50	118 69
KRYPTON	Kr	36	83 80	TITANIUM	Ti	22	47 90
LANTHANUM	La	57	138 91	TUNGSTEN†	W	74	183.85
LAWRENCIUM	Lw	103	[257]*	URANIUM	U	92	238.03
LEAD	Pb	82	207 19	VANADIUM	V	33	50.94
LITHIUM	Li	3	6 939	XENON	Xe	54	131 30
LUTETIUM	Lu	71	174 97	YTTERBIUM	Yb	70	173.04
MAGNESIUM	Mg	12	24 31	YTTRIUM	Y	39	88.91
MANGANESE	Mn	25	54 94	ZINC	Zn	30	65.37
MENDELEVIUM	Md	101	[256]*	ZIRCONIUM	Zr	40	91 22

* A VALUE IN BRACKETS [ ] DENOTES THE MASS NUMBER OF THE ISOTOPE WITH THE LONGEST KNOWN HALF-LIFE

† ALSO CALLED WOLFRAM

The molecular mass is the relative mass of a molecule of a substance as compared to the atomic mass of standard carbon taken as 12 a.m.u.

Sulphuric acid has the formula H_2SO_4 and has two H, one S and four O atoms of atomic masses 1, 32 and 16 respectively. Its molecular mass is, therefore, $(2 \times 1) + (1 \times 32) + (4 \times 16) = 98$. One molecule of H_2SO_4 is 98/12 times as heavy as the standard C atom

The term **formula weight** or formula mass is used with ionic compounds and others where discrete molecules do not exist. Sodium chloride is one such example. The basic formula NaCl is all that can be said. It could be Na^+Cl^- or $(Na^+)_{100}(Cl^-)_{100}$ or $(Na^+)_\infty(Cl^-)_\infty$ The formula mass here is of course the sum of the masses of all the atoms in the formula, and is thus 58.5 For molecules, the molecular and formula masses are the same

4.4 Gram Atomic Mass and Gram Molecular Mass: The Mole

Atomic, molecular and formula masses are just numbers They are relative masses and carry no units such as gram or kg. They are expressed as numbers and as a.m.u. In practice and in everyday use, we want to handle substances in grams or kg quantities. What is the relation between the weight of a substance and those of the atoms or molecules it is made up of? The basic unit is the atom or the molecule We have to find a way to connect the masses of the materials we use everyday with the numbers of atoms or molecules in them. This connection between the everyday world (macroscopic) and the atomic and molecular (microscopic) world is made by the concept of the **mole.** Just as a dozen (12 objects), a score (20) or a gross (144) are used to help in counting objects like bananas, nails, screws or pins, a mole is the scientist's unit for counting atoms, molecules or ions in macroscopic objects.

The mass of a hydrogen molecule H_2 is 2.02 a.m u. and that of an oxygen molecule is 32 a.m.u. 2 02 units of mass of H_2 contain the same number of molecules (one) of H_2 as 32 units of mass of O_2 (also one). If we have two samples, one containing hydrogen gas and the other oxygen gas, and they are in the mass ratio 2.02 32.00, then the first sample must contain exactly as many H_2 molecules as the second contains O_2 molecules If the first contains L molecules in 2.02 grams of H_2 gas, then there must be the same L molecules of O_2 in 32.00 g of oxygen gas. This also means that the number of grams of any compound equal to its molecular mass (also called the gram molecular mass) must contain L molecules. The number of molecules of a compound contained in one gram molecular mass of it will be this fixed number L. This magic number L is actually equal to 6.023×10^{23} and is called the **Avogadro Number** or the **mole.** A mole is thus just a collection of 6.023×10^{23} of the same object It is thus like the atomic or molecular dozen, score or gross, except that it is such a huge number One gram of hydrogen is such a large collection of atoms in fact it has precisely 6.023×10^{23} atoms in it This helps us to calculate the actual mass of an atom.

The number of grams of a compound equal to its molecular mass is called the **Gram Molecular Mass** (GMM). GMM of H_2O is 18 grams

The number of molecules present in 1 GMM of a molecule is equal to the mole and is 6.023×10^{23}

Examples

(a) If 12.00 g of carbon contain 1 mole of carbon atoms, what is the actual mass of one atom of carbon? Mass in grams $= 12.00\text{g}/6.023 \times 10^{23}$

$= 1.99 \times 10^{-23}\text{g}$

The mass of one atom of carbon is $1.99 \times 10^{-23}\text{g}$

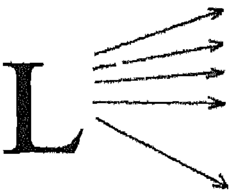
(b) How many molecules of water are there in 1 g of H_2O?

Molecular mass of $H_2O = 18$

18 g H_2O contain 6.023×10^{23} molecules = (1 mole)

1 g H_2O will have $6.023 \times 10^{23}/18$ molecules $= 3.346 \times 10^{22}$ molecules

(c) Aluminium sulphate is $Al_2(SO_4)_3$.



atoms in 1.01 g hydrogen
molecules in 18 g of water (H_2O)
chloride ions in 58.5 of NaCl
molecules in 62000 g of haemoglobin, the protein that gives our blood its red colour.
is called Avogadro Number

(i) Calculate the molecular mass using Table 4 1

(ii) How many molecules are there in 28.5 g of this salt?

(iii) How many gram atoms of each element in 28.5 g of this salt ?

$(2 \times Al) + (3 \times S) + (12 \times O)$

(i) Molecular Mass = $(2 \times 27) + (3 \times 32) + (12 \times 16) = 342$

(ii) Number of moles in 28 5 g = 28.5 g/342 g/mole = 1/12 mole = 0 0833 mole

(iii) Since 28.5 g is 1/12 mole, the number of gram atoms of each element is obtained by multiplying the number of g atoms per mole

1/12 mole $Al_2(SO_4)_3 \times$ 2 g atoms Al/1 mole $Al_2(SO_4)_3$ = 1/6 g atom Al

1/12 mole $Al_2(SO_4)_3 \times$ 3 g atoms S/1 mole $Al_2(SO_4)_3$ = 1/4 g atom S.

1/12 mole $Al_2(SO_4)_3 \times$ 12 g atoms O/1 mole $Al_2(SO_4)_3$ = 1 g atom O.

4.5 How to Determine the Formula of an Unknown Compound

Chemists make various compounds in the laboratory. How do they know what they have made? The compound needs to be identified and its formula determined. The way they do it is to take a little of the compound, break it down and find out the percentages of each constituent element present in it From these percentages, the chemical formula can be found. Let us look at an example. A compound was found to have 75% by weight carbon and the rest hydrogen These numbers are enough to determine the formula.

Let us see how. The ratio by weight of carbon and hydrogen is 75 : 25. The ratio by moles of C and H would be 75/12 25/1 since 12 is the atomic mass of C and 1 that of H. This mole ratio is 6.25 : 25 C·H or 1·4 C:H. The formula of the compound is CH_4 This of course is the empirical or the basic formula The molecule may be CH_4 or C_2H_8 or C_3H_{12} or C_nH_{4n}. If we know the molecular mass of the compound, we can write the actual molecular formula. A molecular mass of 16 gives the molecular formula as CH_4.

Let us look at another example. A compound was found to have 11 2% N, 3.2% H, 41.2% Cr and 44.4% O. What is its formula?

Let us first calculate the moles of atoms of the different elements present in the compound

Element	%	*Atomic Mass*	*No of Moles of Atoms*
N	11.2	14	11 2/14 = 0.8
H	3 2	1	3.2/1 = 3 2
Cr	41.2	52	41.2/52 = 0.8
O	44.2	16	44 4/16 = 2 8

The formula is thus $N_{0.8}\,H_{3.2}\,Cr_{0.8}\,O_{2.8}$

But then we cannot have fractions of atoms, only whole numbers of atoms in molecules Hence, using the common divider of 0.4 in all these, the formula comes out as $N_2H_8Cr_2O_7$.

The problem can be turned around. What is the percentage composition of the elements in ammonia? NH_3 is the formula and the molecular weight is 14 + 3 = 17 The formula shows one N atom and 3 H. Therefore, the percentage composition of N in NH_3 is $14/17 \times 100 = 82.35\%$ and that of H is $3/17 \times 100 = 17.65\%$ The percentage of an element present in a compound can be calculated from the formula

Mass of atoms/Molecular mass × 100

4.6 Balancing Equations

Now that we know how to arrive at formulae and equations, we can represent chemical reactions accurately What do we need for this purpose?

(a) The correct molecular formulae of all the reactants and products.

(b) The condition of the reaction—is energy to be supplied to; or does energy get liberated from the reaction?

(c) To make sure that the total number of atoms is the same, that is, balanced, on both sides. This is called **material balancing.** Remember no atom is destroyed or newly generated in chemical reactions. Therefore, the number of atoms on the left side must match the number on the right The number of molecules can, and often does, change.

(d) To make sure to balance the charges. The same total of charges should appear on the left and right sides of the equation This is because we do not produce only positive, or only negative charges. We always produce them in pairs, so that electrical neutrality is maintained.

With these basic rules, the balance of chemical equations becomes as easy as algebra One can do so by inspection of the formulae of the reactants and products. Here is an example Let us balance the equation.

$Al(OH)_3$ +	H_2SO_4 →	$Al_2(SO_4)_3$ +	H_2O
Aluminium hydroxide	Sulphuric acid	Aluminium Sulphate	Water

The most complicated formula is $Al_2(SO_4)_3$ Let us start with that and balance the elements by adjusting coefficients. There are 2 Al atoms in this case. Let us place 2 in front of $Al(OH)_3$. Likewise, three S atoms (or three SO_4 groups) appear in the formula Hence a coefficient of 3 is needed in front of H_2SO_4 to balance them. Next, balance H atoms. Since 12 H atoms now appear on the left side, we need $6H_2O$ on the right The balanced equation is

$$2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O$$

Material balancing has been done This ensures that the numbers of Al, O,H and S atoms on either side are the same, as are their masses. Let us now balance the equation

KNO_3 →	KNO_2 +	O_2
Potassium nitrate	Potassium nitrite	oxygen

Balancing for the oxygen atoms (3 on the left and 4 on the right) yields a coefficient of 2 in front of KNO_3 and also in front of KNO_2. The balanced equation reads:

$$2KNO_3 \longrightarrow 2KNO_2 + O_2$$

In balancing ionic equations, the charges must also be balanced in addition to balancing the atoms Let us look at the eqution:

$$Al + H^+ \longrightarrow Al^{3+} + H_2$$

If we use a coefficient 2 for H^+, we have

$$Al + 2H^+ \longrightarrow Al^{3+} + H_2$$

the equation balanced atomically but not electrically. To have equal charges on both sides of the equation, let us multiply 2 H^+ by 3 and Al^{3+} by 2. Thus the number of the charges is the same, that is, on both sides.

$$Al + 6H^+ \longrightarrow 2Al^{3+} + H_2$$

Now upon balancing the number of Al and H atoms we get,

$$2Al + 6H^+ \longrightarrow 2Al^{3+} + 3H_2$$

This equation is balanced both with respect to charge and number of atoms.

QUESTIONS

1 What weight in grams is represented by
  (a) 0.40 mole of CO_2?
  (b) 3.00 mole of NH_3?
  (c) 5.14 mole of H_5IO_6?

2 How many atoms of each element are there in 6.3 g of nitric acid, HNO_3?

3 The mass of a single atom of M is 3.05×10^{-22}g. What is its atomic weight? What could this element be? Check in Table 4.1 for possible answers.

4 Calculate the percentage of oxygen in (a) HgO, (b) $K_2Cr_2O_7$, (c) $Al_2(SO_4)_3$.

5 How many grams of Cr are there in 85 g of Cr_2S_3?

6 A compound was found to have 78.2% boron and 21.8% H. Its molecular weight was determined to be 27.6. What is the molecular weight formula of the compound?

7. Translate the following statements into chemical equations and then balance the equations
  (a) Chlorine gas burns in hydrogen gas to give hydrogen chloride
  (b) Barium chloride reacts with zinc sulphate to give zinc chloride and a precipitate of barium sulphate
  (c) Hydrogen sulphide gas burns in air to give water and sulphur dioxide.
  (d) Aluminum metal replaces iron from ferric oxide Fe_2O_3, giving aluminium oxide and iron
  (e) Hydrogen gas combines with nitrogen to give ammonia.
  (f) Phosphorus burns in oxygen to give phosphorus pentoxide
  (g) Sodium metal reacts with water to give sodium hydroxide and hydrogen gas.
  (h) Carbon disulphide burns in air to give carbon dioxide and sulphur dioxide

8 $4HCl + O_2 \longrightarrow 2H_2O + 2Cl_2$ How many moles of HCl are needed to form 0.35 mole of Cl_2?

9 $16HCl + 2KMnO_4 \longrightarrow 2MnCL_2 + 2KCl + 4H_2O + 5Cl_2$ How many moles of chlorine gas will be produced from 3.20 moles of hydrochloric acid?

10 $3CaCl_2 + 2K_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 6KCl$

Calcium chloride	Potassium phosphate	Calcium phosphate	Potassium chloride

How many moles of potassium phosphate are needed to produce 0.076 mole of potassium chloride?

11 In electrolysis, one Na^+ ion picks up one electron to give a Na atom How many electrons are picked up by 23 grams of Na^+ ions? If one electron has a charge of $1\ 6 \times 10^{19}$ coulomb units, what is the total charge picked up by the 23 g of the ions? The number that you get as the answer is called a Faraday (both Faraday and Coulomb were scientists and the units are named after them).

CHAPTER 5

ENERGY CHANGES IN CHEMICAL REACTIONS

INTRODUCTION

WHAT DRIVES a chemical reaction? It is the tendency for the system to reach a lower energy state, just like a ball that rolls downhill to a new position of rest at lower energy A chemical reaction will generally occur if the products have lower energy than the reacting substances or reactants Often we may have to prod or urge the system to get the reaction going by supplying some energy initially. The system will complete the reaction, release the energy and pay back the initial investment and more Let us see how this happens.

5 1 Bond Energy

One way of making NaCl is to react chlorine gas with solid sodium metal. Recall that chlorine gas is the molecular element Cl_2, and Cl_2 needs first to be broken down into Cl atoms Similarly, solid metallic Na needs to be prepared as Na atoms so that the reaction can occur This however is not enough. We need to supply energy to Na atom to ionise it into Na^+. All these steps need energy to be put in:

1 chlorine gas ——→ chlorine atom
$1/2\ Cl_2$ + 119 5 units of ——→ Cl
energy to be supplied

2 solid sodium → Na atom
Na + 109 units of → Na
energy to be supplied

3 Na atom + 493.2 → $Na^+ + e^-$
units of
energy is to be supplied

Energy supplied so far = 721 7 units

The Cl atom picks up an electron and becomes Cl^- ion This step actually releases energy The Cl^- formed is attracted by Na^+ and Na^+Cl^- is formed. This step also releases energy

4. $Cl + e^-$ → Cl^- + 348 2 units of energy released

5 $Na^+ + Cl^-$ → Na^+Cl^- + 769.1 units of energy released

Energy released so far = + 1117 3 units

If we now add up all the steps (1) to (5), we find that we have the chemical equation

$1/2\ Cl_2$(gas) + Na (metal) → Na^+Cl^- (solid)

which says that the reaction will not only occur, but will release (1117 3 − 721 7) = 395.6 units of energy as heat

The unit of energy in these cases is the kilojoule, abbreviated as kJ and is expressed as per mole of the compound Thus, the energy of formation of solid NaCl from its elements is 395.6 kJ per mole or kJ/mole Earlier, the unit used to be kilocalories/mole. The new unit joule is related to the calorie as 1 calorie = 4.2 joules. The term joule is used in honour of the physicist James Prescott Joule, a student of Dalton, who contributed to the study of heat energy in physical and chemical systems. Joule showed that the heat produced in a system is related to the work done.

5.2 Energies Involved in a Reaction

A chemical reaction involves the breaking of bonds in the reactants and the formation of a new bonds to form products. Let us see this in some detail in the example of the formation of water from its elements. In this process, first we need to break the bonds in the hydrogen and oxygen molecules We show this as equations (1) and (2) below Note that both the reactions are endothermic—heat needs to be supplied to break the molecules into atoms (Now you can see why H_2 and O_2 occur in nature as molecular elements and not as atoms). Equation (3) is simply (2) divided by two and is so written as to balance the subsequent reaction (4) Also the (g) in brackets means the gas phase, (l) means liquid and (s) solid

$$H_2\,(\text{gas}) + 435.6\ \text{kJ/mole} \rightarrow 2H\,(\text{gas}) \quad (1)$$

$$O_2\,(g) + 494.6\ \text{kJ/mole} \rightarrow 2O\,(g) \quad (2)$$

$$\tfrac{1}{2}\,O_2\,(g) + 247.3\ \text{kJ/mole} \rightarrow O\,(g) \quad (3)$$

$$H_2(g) + \tfrac{1}{2}\,O_2(g) + 682.9\ \text{kJ/mole} \rightarrow 2H(g) + O(g) \quad (4)$$

$$2H(g) + O(g) \rightarrow H_2O(g) + 924.4\ \text{kJ/mole} \quad (5)$$

$$H_2(g) + \tfrac{1}{2}\,O_2\,(g) \rightarrow H_2O(g) + 241.5\ \text{kJ/mole} \quad (6)$$

Equation (5) describes the reaction between the H and O atoms to form H_2O The reaction is highly exothermic and releases energy When we take away from here the energy we spent in breaking up H_2 and O_2 into atoms, we have equation (6). Note that (6) = (5) − (4).

Equation (6) describes the formation of H_2O from its elements H_2 and O_2. The heat of formation of H_2O is large-241.5 kJ/mole Water is a stable compound, and energry needs to be supplied in order to decompose it.

The heat of formation of CO_2 is 395 kJ/mole. What does this mean? This is the energy we would get if we oxidised carbon

$$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g) + 395\ \text{kJ/mole}$$

This is what we do when we burn charcoal in stoves and ovens in the kitchen. except that the charcoal used is not 100% pure carbon. Also it is burnt in air, which has only 20% O_2. The stoves used are not efficient enough to capture and use all the energy released in the oxidation reaction of the fuel, charcoal.

Is charcoal the best fuel to use? Compare the heats of combustion of some molecules:

$$C + O_2 \longrightarrow CO_2\,(g) + 395\ kJ/mole$$

$$CH_4 + 2O_2 \longrightarrow CO_2(g) + 2H_2O(l)$$
Methane $+ 890\ kJ/mole$

$$C_4H_{10} + 6\tfrac{1}{2}O_2 \longrightarrow 4CO_2(g) + 5H_2O\,(l)$$
Butane $+ 2890\ kJ/mole$

Mole for mole, butane appears to give out more heat on burning than carbon does, about 7 times more Remember, however, that a mole of butane weighs 58 grams, while a mole of carbon weighs 12 grams Thus, weight for weight (in grams) butane releases about five times more energy upon burning than carbon Butane, incidentally, is the main constituent in the cooking gas used in kitchens (liquified petroleum gas or LPG).

We have so far been discussing the heat involved in oxidation reactions. In general, any reaction may release or absorb energy as heat For example, the formation of ammonia from its elements releases heat

$$N_2(g) + 3H_2O(g) \longrightarrow 2NH_3(g) \quad + 92\ kJ$$

when two moles of NH_3 are formed, the heat released is 92 kJ or 46 kJ/mole.

5.3 Other Forms of Energy in Chemical Reactions—Photochemistry

Heat is not the only form of energy involved in chemical reactions Some reactions produce light while other reactions occur upon the absorption of light energy. These are called **photochemical reactions.** The most important example of a photochemical reaction is photosynthesis that plants carry out in sunlight Here are a few more examples The molecule I_2 dissociates into two iodine atoms when it absorbs visible light. Hydrochloric acid can be formed by irradiating a flask containing the gases Cl_2 and H_2 Chlorine atoms are produced photochemically first, and they start a chain or a relay reaction

$$Cl_2 \longrightarrow 2Cl \quad \text{light}$$
$$Cl + H_2 \longrightarrow HCl + H$$
$$H + Cl_2 \longrightarrow HCl + Cl$$

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. .. .

. . ..

Photography uses a photochemical reaction. The photographic film contains the compound AgBr (silver bromide) When light falls on the film, this compound is chemically affected On developing the film, the photographic image is obtained

Also,some reactions in the atmosphere occur upon light absorption Gases like NO_2 and SO_2 are given out from the chimneys of industrial firms. They absorb sunlight and produce reactive atoms **(Free Radicals),** which further react with other molecules in air Some of the compounds so formed are toxic, and harmful to health—they cause atmospheric pollution Exhaust fumes from cars, lorries and motor cycles often release NO_2, SO_2 and similar oxides that produce such **photochemical** pollution material Hence the need to control automobile exhausts

Electrochemistry

We have already seen that electrical energy can be used to carry out some chemical reactions Water, for example, can be electrolysed as

$$2H_2O(l) \xrightarrow[\text{current}]{\text{Electrical}} 2H_2(g) + O_2(g)$$

We saw that the reaction between Cl_2 and Na produces NaCl and releases energy The reaction involved the transfer of electrons from Na to Cl. The reverse reaction would occur if energy were supplied to NaCl. A convenient way of doing so is to pass electricity through NaCl, in other words, to electrolyse NaCl Figure 5.1 shows an electrolysis cell. Electricity from a battery is passed through molten NaCl, using two electrodes. The positive electrode is anode and the negatively charged electrode is called the cathode Molten NaCl is used so that electric current can pass easily through the medium.

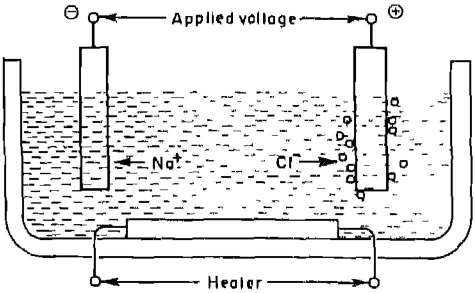


Fig. 5.1 *Electrolysis of molten sodium chloride*

What do we mean when we say electricity is passed? It means that electrically charged particles are sent through a medium. These particles would be ions or simply electrons. And when electricity causes a chemical reaction, we call the process **electrochemistry**. Electrochemistry, therefore, involves electrons reacting with atoms and molecules, that is, the transfer of electrons fron one particle to another. The energy released or absorbed in this process is usually electrical in nature.

In the electolysis cell shown in Figure 5.1, electrons enter the molten salt from the cathode and when the circuit is complete, they leave the medium at the anode and return to the battery. Na^+ ions from the medium would move towards the cathode since it is negatively charged. At the cathode, they pick up electrons and become Na atoms, which will be deposited at the electrode surface

At cathode : $Na^+ + e^- \longrightarrow Na$

At anode : $Cl^- \longrightarrow \frac{1}{2} Cl_2 + e^-$

Net reaction : $Na^+ + Cl^- \rightarrow Na + \frac{1}{2}Cl_2$

At the other electrode, the anode, chloride ions release electrons and become Cl_2 gas which escapes from the cell. Overall, electrical energy is used up and NaCl produces Na metal and chlorine gas.

In fact, both sodium metal and chlorine gas are manufactured in industry by the electrolysis process. This is also true of many other metals such as Mg, Al, or Cu.

Electrochemical Cells

The reverse processs where electricity is produced by a chemical reaction is of great interest too. Many displacement reactions of metallic compounds generate electrical energy.

$$Zn(s) + CuSO_4(aq.) \rightarrow ZnSO_4(aq.) + Cu(s)$$

In the above reaction, mobile zinc displaces copper from a solution of copper sulphate in water (hence aq , aqueous) and metallic copper is released When the concentrations are properly chosen this reaction will produce electricity This discovery was first made by the Italian scientist Luigi Galvani The apparatus where the above reaction is conducted and electricity released is called an **electrochemical cell.** It is also called a **galvanic cell** in honour of Galvani. The activity below tells you how to make this cell and study it

Activity 1

Reaction of Zinc with Copper Sulphate Solution

The materials required are a sheet or rod of zinc, copper sulphate solution, and a beaker or tumbler

Take the copper sulphate solution in a beaker Put the sheet or rod of zinc in the solution and observe You will see a shining red deposit of copper metal on the surface of the zinc rod The reaction is fast and can be seen easily within 10-20 minutes.

In the activity the zinc metal forms zinc ions in the solution giving up electrons The electrons are accepted by copper ions to form copper metal.

$$Zn(s) + Cu^{2+} \longrightarrow Zn^{2+} + Cu(s)$$

The metals can be arranged in order of their reactivities such as sodium > magnesium > aluminium > zinc > iron > lead > hydrogen > copper > mercury > silver > gold The metal higher in the reactivity series is more reactive and has a greater tendency to form positive ions The more active metal can displace the less active metal from solution This is why Zn displaced Cu. Generally, more reactive metals readily undergo chemical reactions involving the formation of ions. This is why most of the metals in nature are found in the form of ionic compounds. Only metals such as gold, which are least reactive, are found in the metallic state

Recall Activity 3 of Chapter 4. The reactions we studied there, are actually electrochemical

The Dry Cell

The dry cell (dry battery) used in torches, transistor radios and toys was invented by G Le Clanche in 1868 If you cut open a dry cell, you will find a carbon rod in the centre The outer part of the cell is made of zinc. The cell is filled with a paste of ammonium chloride Around the carbon rod is a black paste of manganese dioxide, carbon and ammonium chloride The dry cell gives a voltage of 1.5 volts.

The zinc covering undergoes a chemical reaction and produces zinc ions and electrons. The reaction which uses up electrons involves manganese dioxide. The dry cell gives a steady flow of electrons at 1 5 volts. There are several other varieties of dry cells called **silver cells** or the **lithium cell** which are used in calculators, watches and cameras.

Storage Cells

Most electrochemical cells cannot be recharged after they are run down This means that the chemical changes taking place cannot be reversed by supplying an electric current However, there are some cells called **accumulators or storage cells** which can be recharged and used again and again as a source of electric current. The most widely used is the lead storage cell used in cars and other vehicles This cell consists of several plates of lead dipped in sulphuric acid When they are kept for some time, a deposit of lead sulphate forms on them. When electric current is passed through this cell, one series of lead plates form PbO_2, while on the other series of lead plates, the lead ions are deposited as lead. The cell now gives electric current and undergoes opposite chemical reactions. This cell can be recharged by passing electricity through it.

Some other storage cell are nickel-iron and nickel-cadmium storage cells

5 4 Metallic Corrosion

Many metals are corroded when they are exposed to the environment A coating of rust is formed on the surface of iron in the presence of moisture and air. The process of corrosion is speeded up when two metals are in contact with each other. The metals form an electrochemical cell in the presence of moisture and the more active metal forms compounds. Rusting of iron can be prevented by coating with zinc. When exposed to humid air, zinc will form zinc compounds and protect the iron from rustings. As long as some zinc coating remains, iron will not rust This type of coated iron is called **galvanised iron or G.I.** Do you see why the word **galvanised** is used here?

QUESTIONS

1 The heat of combustion of carbon is 395 kJ/mole What is the amount of heat liberated when one kg of pure carbon is oxidised to CO_2?

2. The heat liberated by 1 kg of carbon is used totally to heat 15 litres of water (at 25°C) What will be the final temperature of the water? Remember that (1 calorie = 4.18 J, and the specific heat of water is 1 cal/degree/gram).

3. Mercuric oxide yields mercury upon heating

$$2HgO + 180\,kJ \longrightarrow 2Hg + O_2$$

What is the heat of formation of HgO? Choose the right answer from:
(a) 180 kJ/mole; (b) 90 kJ/mole; (c) 900 kJ/mole; (d) 5.66 kJ/mole

4. What would be the amount of heat needed to decompose 54 gram of HgO? And how many grams of Hg would be obtained?

5 The heats of combustion of a sugar, $C_6H_{12}O_6$, related to starch, and of cyclohexane, C_6H_{12}, related to fats and oils, are given below.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 2825\,kJ/mole$$
$$C_6H_{12} + 12O_2 \longrightarrow 6CO_2 + 6H_2O + 3950\,kJ/mole$$

Which of the two gives more energy *per gram*?

6 From the information in Q. 5, can you tell which would give more energy to the body, fat or starch? Why?

7 Recall that the faraday is a mole of electrons and is about 96500 coulombs of

electric charge (see Q 11 of Chapter 4). How many faradays are released when 12.91 g of copper metal is changed into copper ions, Cu^{2+}?

8 The coulomb is the unit of electrical charge and is related to the ampere, the unit of electric current as

$$\text{coulomb} = \text{ampere} \times \text{time in seconds}$$

A current of 16 amperes was passed through the electrolysis cell shown in Figure 5 1, for a period of 100 5 minutes How many coulombs were used up? How many grams of Na metal were obtained?

9 The reaction $Zn \longrightarrow Zn^{2+} + 2e^-$ releases 0.76 volts (V) of elecricity. But the reaction $Cu \longrightarrow Cu^{2+} + 2e^-$ needs a supply of 0 34V for it to occur Now, what will be the total electricity in volts produced in the reaction below? Choose the right answer.

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$$

Choose from: (a) 1.10V, (b) 0.42 V; (c) 0.76 V, (d) 0 34 V.

10. Which would occur more readily in nature as metal, and which as ion: zinc or copper?

11. Why is iron galvanised with zinc? Can it be galvanised with copper? If not, why

12 Describe a dry cell.

CHAPTER 6

DESCRIBING MOTION

INTRODUCTION

WE CONSTANTLY see things moving around us. Some of them move from one place to another. Cars move on the road and aeroplanes fly from one city to another Some objects stay at the same place and go around like the blades of the fan on your ceiling. In a sewing machine, for example, your legs pedal, the wheels move around, the needle moves up and down and the cloth moves ahead. During the day the sun appears to move across the sky and at night the moon and stars appear to go around us Sometimes we cannot see motion but can only infer that something is moving. For example, we can never see air moving but can only detect its motion when it moves light objects like dust, grass or the blades of a windmill

In this chapter we shall learn to describe some simple types of motion. We must now learn to describe the position of a moving object as time passes Whenever we describe the location of an object we specify its position with respect to a fixed landmark. "The railway station is 2 km north of the school" describes the location of the railway station with respect to the fixed landmark, the school. Similarly we describe the motion of an object by specifying how its position changes with respect to a fixed point. Such a fixed point is called the "*origin*" To describe the position of the object we specify its distance and direction from the origin As an object moves, its distance from the origin and its direction with respect to the origin can change

However,in this chapter we shall learn to describe the motion of only those objects which move in a straight line. A bus moving on a straight road, a train moving on a straight track or a runner running in a straight line are examples of this type of motion.

If an object does not move in a

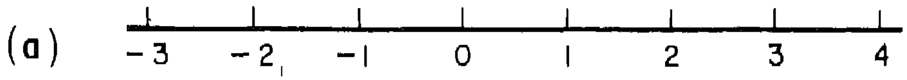


Fig 6.1 a *Position of an object on a straight line path*

straight line, we have to specify the distance through which the object has shifted and the direction in which it has been shifted But for objects which move in a straight line the description is simpler. For example, we could say that the position of a bus was 2 km from the origin (Figure 6 1a) at 12.00 noon and at − 1 km at 12 10 p m

Notice that the points to the left of the origin are negative and those on right are positive. *The change of position of an object is called its displacement* If the position of the object changes from x_1 to x_2 the displacement d is given by

$$d = (x_2 - x_1)$$

The sign of the displacement 'd' tells us the direction in which the object has been shifted If the object has been moved to the right 'd' is positive. If the object has been moved to the left 'd' is negative.

6.1 Speed

Some objects move fast and some slowly and we need a method to decide which object moves faster. In some cases, it is easy to decide this. For example, can you decide from the information given below which of the two cars moves faster—Car I or Car II?

	Car I	*Car II*
Starting time from A	9 00 a.m	9 00 a.m
Arrival time at B	11.00 a m	10.20 a m

Since the two cars start at the same time and Car II reaches point B earlier, you will have no hesitation in deciding that Car II moves faster.

In some cases, it is not so easy to decide which moves faster. The Rajdhani Express travels from Bombay to Delhi—a distance of 1384 km It starts from Bombay at 4.00 p.m and reaches Delhi at 9.00 a.m the next day The Trivandrum Express travels from Guwahati in Assam to Trivandrum in Kerala. It starts from Guwahati on Sunday night at 11.30 p.m. and covers 3574 km reaching Trivandrum at 10.30 p.m on Wednesday.

These trains not only start and reach their destination at different times; they also move different distances How will you decide which of the two trains moves faster?

Comparison of the motion of such objects becomes easier if we compare the distance moved by them in one unit of time The unit of time chosen could be one second (symbol: s), one minute (symbol: min) or one hour (symbol: h). The distance moved by an object in unit time is called its average speed

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Time taken to travel that distance}}$$

The Rajdhani Express travelled a distance of 1384 km in 17 hours. Its average speed is, therefore, 81.4 km/hour Can you now find the average speed of the Trivandrum Express and compare it with the average speed of the Rajdhani Express?

The Rajdhani Express, like any other train, does not always travel at the same speed It stops at railway stations, where its speed is 0 km/h. Between stations it moves with a speed greater than the average speed. We, therefore, have to be careful and use the word *average,* when we talk about the ratio of total distance travelled to the time taken

Table 6.1

SPEEDS OF SOME OBJECTS

Average speed of a tortoise	0.5 km/h
Average speed of a man walking at a steady pace	6 km/h
Average speed of sprinter P.T. Usha in the 200 metres dash	30.72 km/h
Maximum speed of a bee	16 km/h
Maximum speed of a cheetah	96 km/h
Maximum speed of falcon	152 km/h
Maximum speed of the fastest train ("The trains of great speed" in France)	255 km/h
Wind speed in a light breeze	32 km/h
Wind speed in a hurricane	320 km/h
The speed at which the earth goes round the sun	107,200 km/h = 1.072 × 10^5 km/h
The speed at which light travels	1,080,000,000 **km/h** = 1.08 x 10^9 km/h

If a car travels 80 km in two hours its average speed will be 40 km/h. But if distance is measured in metre, its average speed would be 40000 m/h. Can you find the average speed of the same car if time is measured in minutes?

The speed of the same object (in this case, a car) has different numerical values in different sets of unit. Whenever we have to compare any two quantities, as in this case we must take care to express these quantities in the same units. Table 6.1 compares the speed of several objects in units of km/h.

Exercise

Arrange the following speeds in increasing order

(1) Bicycle moving with a speed of 18km/h
(2) A fast runner running with a speed of 7 m/s
(3) A car moving with a speed of 2000 m/min

6.2 Distance —Time Tables

Ravi travels in a bus from the city to visit a friend in a nearby village. The road on which he is travelling has a stone on the side after every 10 km. Being curious, he decides to note the time at which each stone appears. After some time he makes the following table (Table 6.2). From this table, can you find the distances travelled by the bus between 9.30 a.m and 9.45 a.m.; 9.45 a.m. and 10.00 a.m., and 10.45 a.m. and 11.00 a.m.?

Table 6.2

Time	*Distance*
9.30 a.m	10 km
9.45 a.m.	20 km
10.00 a.m.	30 km
10.15 a.m.	40 km
10.30 a.m	50 km
10.45 a.m.	60 km
11.00 a.m.	70 km

If you calculate these distances you will find that the bus moves equal distances in equal intervals of time. That is, the bus moves 10 km in the first 15 min, 10 km in second 15 min; 10 km in the third 15 min and so on.

When an object moves equal distances in equal intervals of time we say that it moves with uniform speed

From Table 6 2 we can tell the precise position of Ravi's bus at particular times only The table does not tell the position at 9 35 a.m or 10 25 a.m or for that matter at any time not mentioned in the table To predict its position at any intermediate time we need a relation between distance, time and speed Let us find that relation for an object moving with uniform speed along a straight line Let us measure all distances to the right of the fixed point O (Fig. 6 1b).

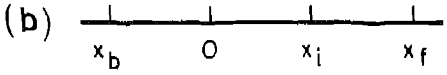


Fig 6 1b

If the object travels from point x_i to point x_f in time t with uniform speed v, then

$$v = \frac{\text{distance travelled}}{\text{time taken}} = \frac{x_f - x_i}{t}$$

It follows that *distance* = v × t or

$$x_f = x_i + vt \qquad \text{.. (Equation 6.1)}$$

Exercise

Since Ravi's bus moved at a uniform speed of 40 km/h can you make a table giving the distance travelled by the bus after every 10 min (instead of 15 min in Table 6 2), or 20 min (instead of 15 min in Table 6.2).

How long would this table be if you had to fill in the position after every 2 minutes instead of 15 min or 20 min? Making such a table would be a cumbersome exercise.

6 3 Graphs and Their Uses

We learnt to make a table giving the position of a moving object at different times But if we need to know the positions after very short intervals of times, the table would be very long indeed Even a table of this type does not tell you much. For example, to decide whether the object is moving at uniform speed, you will have to find the distance travelled in successive intervals and check if they are equal This could be very tiresome if you have a long table.

Such tables are used very often in science. For example, given below is the weight of a chicken at different times as it grows What does the table tell you?

Age	*Weight*
1 day	40g
1 week	100g
2 weeks	300g
4 weeks	600g
6 weeks	1000g
8 weeks	1700g
10 weeks	1800g
12 weeks	1800g

There is a way of making the above table more informative. You can plot a graph of the weight of the chicken on one axis and its age on the other axis Such a graph would tell you at a glance how the weight of the chicken changes as it grows This graph has been plotted in Figures 6 2a and 6 2b.

You can now immediately see that the chicken grows gradually in the first 10 days, after which its weight increases

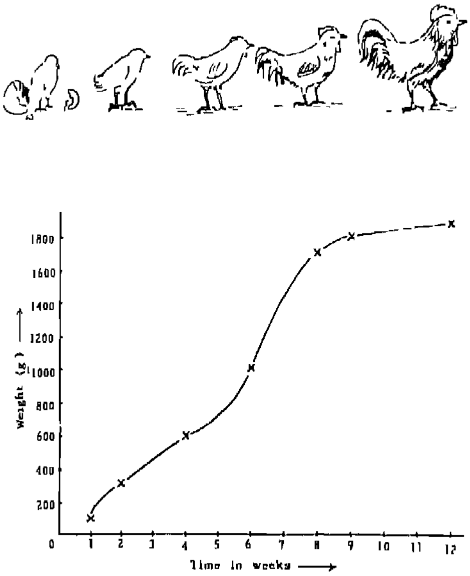


Fig 6.2a,b *Weight — age graph for chicken*

rapidly. The graph in the region between 6 weeks and 8 weeks rises very steeply. After about ten weeks its weight increases, but very slowly. After it reaches an age of 12 weeks, its weight almost stays the same. In fact if you take a table of the weight and age of a man or a woman it may look very different from that of a chicken. But if you plot a graph of weight against age for humans (Figure 6.3) with the proper scale, it will not look very different from that of a chicken. Comparison of these two graphs can tell us a lot about how living things grow. Much more in fact, than the two tables.

THE AGE AND THE WEIGHT OF A MAN

Age	*Weight*
1 day	3.2 kg
1 year	9.6 kg
2 years	11.1 kg
4 years	15.5 kg
7 years	21.1 kg
9 years	24.9 kg
12 years	29.2 kg
14 years	36.1 kg
16 years	46.1 kg
20 years	68.2 kg
22 years	71.3 kg
24 years	72.2 kg

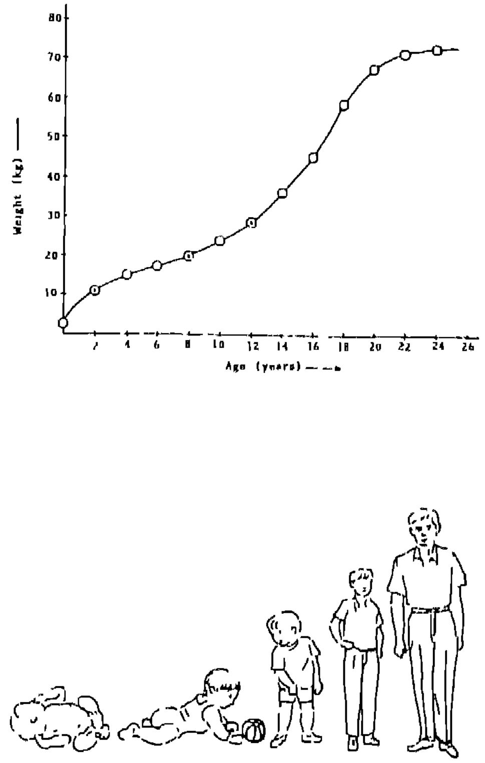


Fig 6.3 *Weight — age graph for human beings*

To discover more about the motion of Ravi's bus, let us plot a graph of the position of the bus on one axis and the time on the other (Figure 6.4). From the graph we can find the position of Ravi's bus at any time. This can be done by reading the height of the point on the graph corresponding to the desired time.

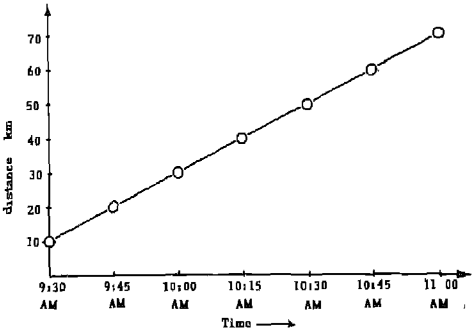


Fig. 6 4 *Graph showing position of bus at different instants of time*

Exercise

Find the position of Ravi's bus at 9.55 a m. You can also find the position from Equation 6 1 and check if they give the same answer

Having plotted the graph let us now learn to interpret it.

1. The distance-time graph of an object moving at uniform speed is always a straight line When an object moves with uniform speed it covers equal distances in equal intervals of time In the above example, the distance covered by Ravi's bus from 9 30 a.m to 10 00 a m. is represented by the length AB in Figure 6.5. The distance covered from 10.15a.m. to 10 45 a.m is represented by the length PQ. You can check that length AB and the length PQ are equal

A straight line graph will tell you at a glance that the object moves with uniform speed, whereas in a table you would have to calculate distances covered in successive intervals to see if they are equal

2. The speed of a moving object can also be found from the distance-time graph For example, in Figure 6 5 the time taken to travel a distance AB (20 km) is shown by CB (30 min) We know that

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}} = \frac{AB}{CB}$$

This ratio of AB divided by CB is also called the slope of the line You can now find the speed of any object moving with uniform speed by calculating the slope of its distance-time graph For uniform motion it does not matter where you draw the triangle ABC. For example, if you draw it at PQR, the ratio $\frac{PQ}{QR}$ will be the same as $\frac{AB}{CB}$.

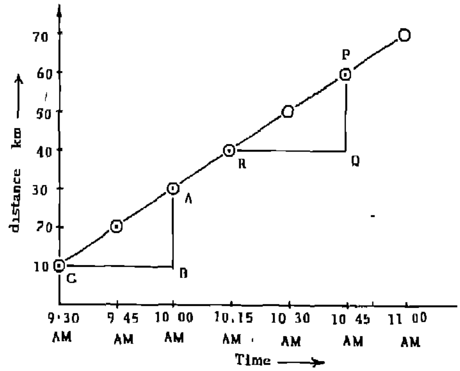


Fig 6 5 *Distance - Time graph*

Exercise

1. Plot the distance-time graph of a body at rest (that is, not moving) at a distance of 100 cm from the origin.
2. Figure 6.6 shows the distance-time graph of two objects moving with uniform speed. Which of the two has

a greater slope? Which of the two objects is moving faster?

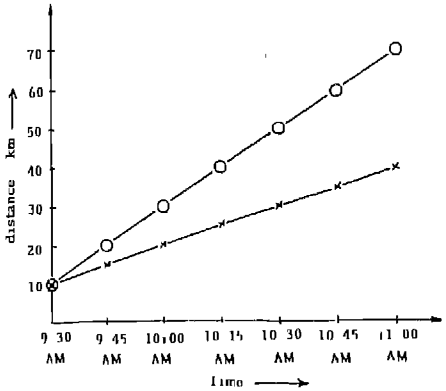


Fig. 6.6 *Distance-time graph of two objects moving with uniform speed*

We have seen from the preceding examples that a distance-time graph for a moving object is more efficient in describing the motion than its distance-time table.

Plotting a graph is even more advantageous when we want to compare the motion of the objects. Let us look at the following example. Ahmed's friend started from Ahmed's house at 10.00 a.m. on a bicycle. His distance-time table is given in Table 6.3.

Table 6.3

DISTANCE-TIME

Time	*Distance*
10.00 a.m.	0 km
10.15 a.m.	4 km
10.30 a.m.	8 km
10.45 a.m.	12 km
11.00 a.m.	16 km
11.15 a.m.	20 km
11.30 a.m.	24 km
11.45 a.m.	28 km
12.00 noon	32 km

At 11.00 a.m. Ahmed starts on a motor cycle and travels at a speed of 40 km/h. Can you find the time at which Ahmed catches up with his friend?

Let us construct the distance-time table of Ahmed's motion since we know that he is travelling at a uniform speed of 40 km/h. We can use the relation between speed, time and distance (Equation 6.1) to construct this table.

Time	*Distance*
11.00 a.m.	0 km
11.15 a.m.	10 km
11.30 a.m.	20 km
11.45 a.m.	30 km
12.00 noon	40 km

These tables do not directly tell us the time and place where Ahmed overtakes his friend. However, the distance-time graph of the motion of the two friends will.

The graph of the motion of the these two friends has been plotted in Figure 6.7.

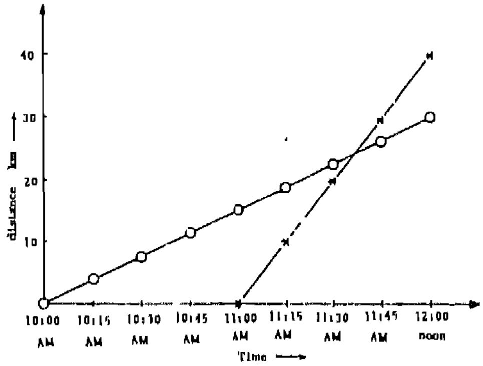


Fig 6.7 *Distance-time graph of two motions*

Can you now use these graphs to find: (1) the time at which Ahmed overtakes his friend? (2) how far were they from Ahmed's house when they met? (3) what was the distance separating the two friends at 11 00 a m and 11.35 a.m.?. (4) if Ahmed's friend had travelled at a speed 12 km/h, would Ahmed catch him earlier or later? (5) if Ahmed had travelled at a speed greater than 40 km/h would he meet his friend earlier or later? Ascertain this by using the graph

6 4 Speed-Time Graph

The distance travelled by an object moving with uniform speed is given by the relation

distance = speed × time

This distance can also be found using a graph of speed and time If an object moves at uniform speed, the height of its speed-time graph will not change with time It will be a line parallel to the X – axis Figure 6.8 shows the speed-time graph for an object moving with a uniform speed of 55 km/h.

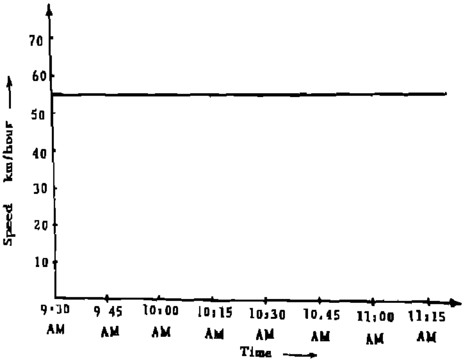


Fig.6.8 *Speed-time graph for uniform motion.*

The distance covered by this body from time t_1 to time t_2 is given by

$$\text{distance} = 55 \times (t_2 - t_1)$$

The speed of 55km/h is represented by the height AD or BC and the time ($t_2 - t_1$) represented by the length AB in Figure 6.9

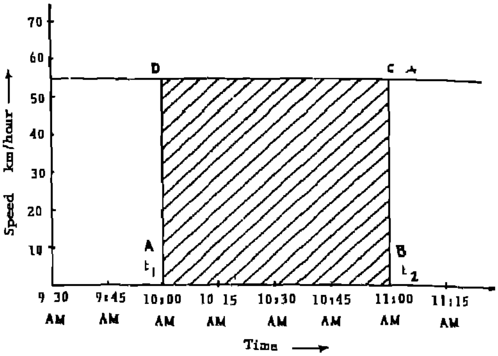


Fig. 6.9 *Computing distance with a speed-time graph.*

The distance travelled can also be expressed as

distance = AD × AB

= Area of the rectangle ABCD (shaded in Figure 6.9)

Let us consider an example. The speed-time graph of an object is shown in Figure 6 10 Find the distance travelled from 10.20 a.m.—10 40 a m.

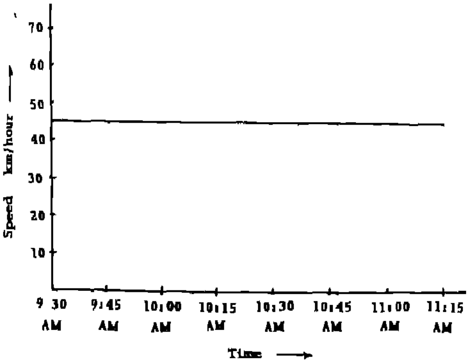


Fig 6.10 *Speed-time graph*

6.5 Velocity

We have learnt to describe the motion of objects travelling in a straight line with constant speed. If we know the speed at which these objects travel, we can predict their distance at any desired time. However, knowing the speed is often not enough in predicting the position of moving objects. In addition to the speed we also need to know the *direction* in which an object moves. For example, look at Figure 6.11. It shows a boy about to leave his house. Can you predict his position after an hour if you are told that he walks with a uniform speed of 4 km/h? To predict his position you would also need to know the road he is going to take, that is, the direction in which he is going.

We can specify this direction in many ways. The simplest way is to state it with respect to the four directions that we already know—north, south, east and west. For example, we could say that an object A moves at a speed of 30 km/h in the north direction or that another object B moves at a speed of 5 km/h in the direction 30° east of north.

We commonly use a single word to describe both the speed at which the object moves and the direction in which it moves. The word is *velocity*. For example, instead of saying a car moves with a speed of 60 km/h in the direction 45° south of west, we say that the car moves at a velocity of 60 km/h, 45° south of west. Notice how the two words—speed and direction have been dropped in the second statement, and a single word, velocity, has been used in their place.

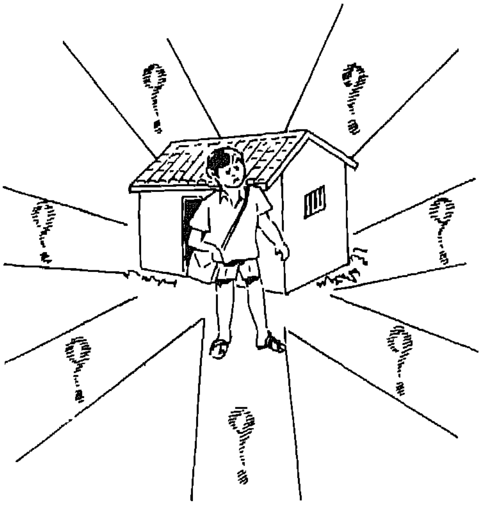


Fig.6.11

VECTORS

Quantities which need both magnitude and direction for their complete description are called "*vectors*". Velocity is a vector quantity. We had come across another vector quantity before, the displacement of an object. If an object does not move in a straight line we have to specify both the distance through which the object is displaced and the direction in which it is displaced. Specifying only one of these does not describe the displacement completely (see for example Figure 6.11)

How do we represent such quantities on paper? One way to do this would be to write out both the magnitude of the vector and its direction in words For example, "The velocity of an object is 30 m/s, 30° south of west."

However, such a description can be quite clumsy A better way of representing vectors is by directed line segments(arrows). The length of the arrow tells us the magnitude of the vector. The direction in which the arrow points gives the direction of the vector

For example, the velocity 30 m/s 30° south of west is represented by the arrow in Figure 6.12.

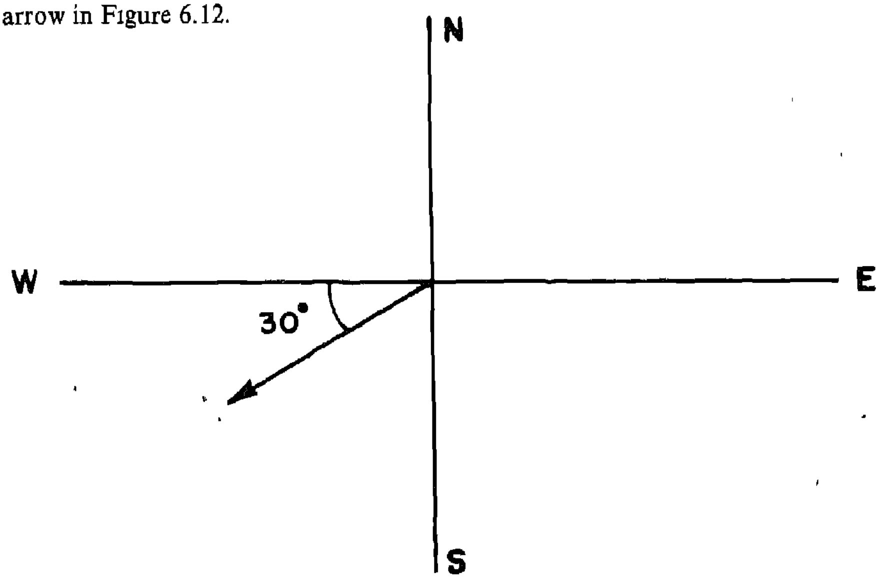


Fig.6.12 *Graphical representation of a vector*

We can choose any convenient scale If we choose the scale 1cm = 5 m/s, the length of the arrow would be 6 cm. Similarly the displacement of 5 km to the north would be represented by an arrow of length 2 cm pointing north. The scale chosen in this case is 2.5 km = 1 cm

If an object moves with uniform speed in a straight line neither its speed nor its direction of motion changes. We then say that the object moves with uniform velocity. If however, its speed or its direction of motion changes as in a bus turning at a junction, we say that its velocity has changed

6.6 Non-Uniform Motion: Acceleration

Objects very rarely move with uniform speed A train starting from the station moves a very small distance in first second It moves a little more distance in the next second After some time it moves as much as 20 m in one second. As it approaches the next station the distance covered per second decreases.

The distance-time graph of the motion of a train leaving station is shown in Figure 6.13. From this graph find the

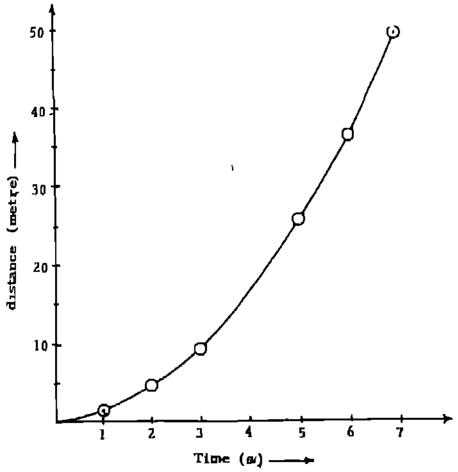


Fig.6.13 *Distance-time graph for the motion of the train*

distance travelled by the train in the first second, i.e (t = 1 s) next second, (t = 2 s) and the third second (t = 3 s) Since the train travels different distances in one second, its speed changes with time. Note that the distance-time graph is not a straight line This is an example of non-uniform motion.

Exercise

The speed of an object can change in several ways A few speed-time graphs for non-uniform motion of objects moving along a straight line are shown in Figures 6.14 a, b, c and d

Which of these graphs represent the motion of a body whose speed is (a) increasing with time, (b) decreasing with time, (c) uniform, (d) oscillating?

We have seen earlier that to describe the motion of any object we have to state both its speed and the direction of motion That is, we have to state its velocity.

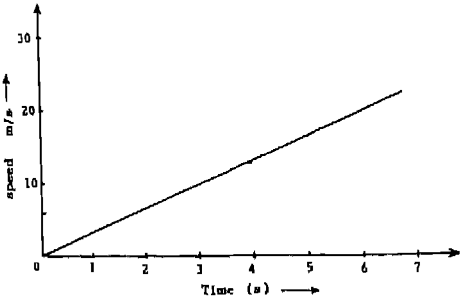


Fig.6.14a

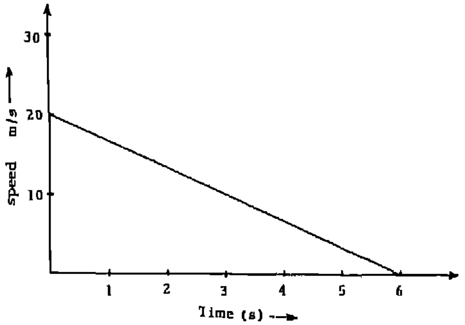


Fig.6 14b

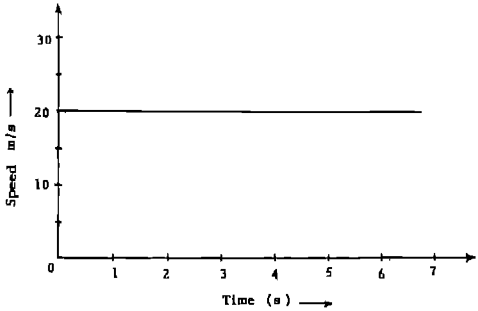


Fig.6 14c

When an object does not move with uniform velocity, its velocity changes with time. We use the word *acceleration* to indicate the change of velocity with time.

When the velocity of a body changes with time we say that the body is accele-

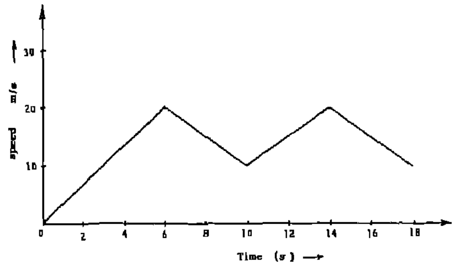


Fig 6.14d

rating This change could be a change in its speed or direction of motion or both.

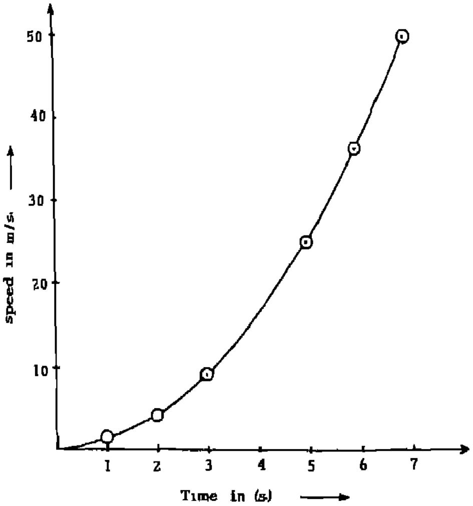


Fig.6.15a *Speed-time graph for a non-uniformly accelerated motion*

For graph in Fig.6 15a find the change in speed from the 1st second to the 2nd second and from the 4th second to the 5th second. Similarly, find the change in speed for the same time intervals for the motion shown by the graph in Fig. 6.15b

The speed of the object in Fig 6.15b changes in a very special way. The change in the speed is the same in equal time intervals. This is not so for the graph in Fig.6.15a.

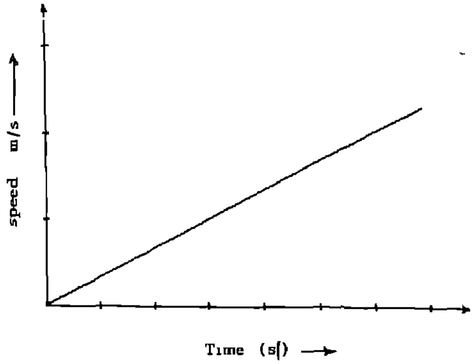


Fig. 6.15b *Speed-time graph for a uniformly accelerated motion*

6.7 Circular Motion

When the velocity of an object changes we say that the object is accelerating. This change could be a change in the speed or a change in its direction of motion. Can you think of an example where an object does not change its speed but only its direction of motion? Let us see an example of this type of motion.

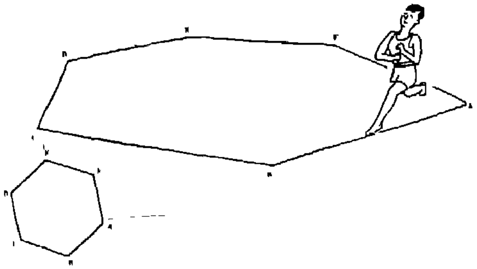


Fig.6.16 *A boy running along a haxagonal track*

Figure 6 16 shows a boy running on a track which has the shape of a regular hexagon. A regular hexagon is a closed figure which has six equal sides Let us assume that the boy runs at uniform speed on the straight parts of the track (AB, BC, CD, DE, EF, FA) At the turns he quickly changes his direction of motion to stay on the track, but does not change his speed How many times will he have to change his direction of motion? You must have noticed that to move in a hexagon, he has to do this 6 times. What if the track were not a hexagon but a regular octagon, with eight equal sides as shown in Figure 6 17a? To stay on the track he will have to turn eight times As the number of sides of the track increases he has to turn more and more often. For example, in Figure 6 17b the track has 20 sides and the boy now has to turn 20 times

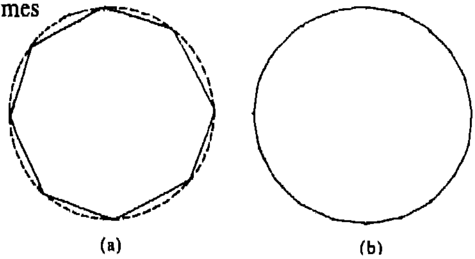

(a) (b)

Fig.6.17 *A circular track can be considered as a polygon of infinite sides*

What would happen to the track as we go on increasing the number of sides indefinitely? If you do this you will notice that the shape of the track approaches the shape of a circle. And to move on this circle the runner will have to change his direction of motion at every instant of time. After all he is running on a polygon with many many, in fact infinite sides.

Motion in a circle at constant speed is, therefore, an example of accelerated motion. Though the speed may not change, the direction of motion changes constantly..

When an object travels in a straight line its direction of motion does not change. In this case its acceleration is just the rate of change of speed with time *If the object has speed* v_1 *at time* t_1, *and speed* v_2 *at a later time* t_2 *its acceleration is defined as*

$$\text{acceleration} = \frac{v_2 - v_1}{t_2 - t_1}$$

If the velocity of an object changes by equal amounts in equal intervals of time, we say that the object moves with uniform acceleration For example, let us look at the speed-time graph shown in Figure 6 18. The increase in speed from time t_1 to t_2 is represented by some length The increase in speed from time t_3 to t_4 is represented by another length. The time intervals $t_1 - t_2$ and $t_3 - t_4$ shown in this graph are equal. Since the lengths are also equal, the graph represents an object travelling with uniform acceleration. The speed-time graph of an object travelling with uniform acceleration is a straight line. The acceleration of such an object is just the slope of this straight line.

The units of acceleration depend on the units in which the distance and time are measured If distance is measured in metres and time in seconds the units of velocity will be metre per second and the unit of acceleration will be metre per second per second. Instead of writing metre per second per second the units of acceleration are usually written as m/s^2.

We have learnt to find the distance travelled by an object travelling at uniform speed in any given time interval. We can do this either by using the relation—distance travelled = speed × time interval—or by finding the area under the

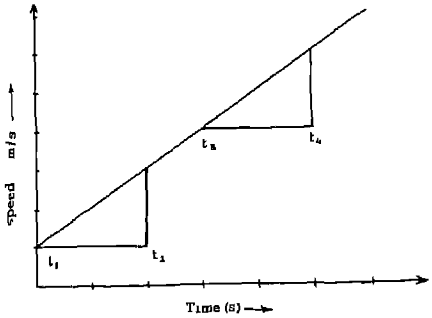


Fig 6 18 *Speed-time graph of a uniformly accelerated motion*

horizontal speed-time graph of such an object. For example, in Figure 6.9, the area of the rectangle ABCD (shaded) is the distance travelled in that interval. This is

distance travelled = area under the speed-time graph for the given time interval.

For objects which do not move with uniform speed, we can no longer use the equation—distance=speed × time — because the speed changes with time. However, the second relation given above can be used even for objects moving with changing speeds Let us try to understand why this is so Let us look at the speed-time graph in a manner similar to the way in which we studied an object moving in a circle There we discovered that a circle is nothing but a polygon with infinite sides. Let us start with a speed-time graph shown in Figure 6 19

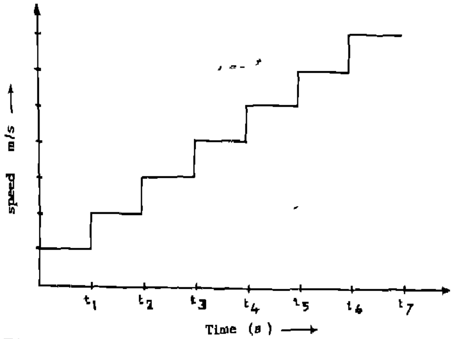


Fig. 6 19 *Speed-time graph showing stepwise increase in speed*

The graph shows that the speed of the object increases in steps In between the time t_1 and t_2 or t_3 and t_4 or t_5 and t_6 the speed remains constant, but jumps to a higher value at t_1 t_2 t_3 and so on What would be the total distance covered by this object from time 0 to t_7? To find this distance let us add up the distances covered in each of the intervals

Total distance travelled
from 0 s to t_7 s =

distance travelled in time $0 \to t_1$ +
distance travelled in time $t_1 \to t_2$
+ distance travelled in time $t_2 \to t_3$

+ distance travelled in time $t_6 \to t_7$

The distances travelled in these time intervals can be easily found since the object travels with uniform speed within these intervals (Figure 6.20).

Distance travelled in time $0 \to t_1$ =Area of the rectangle AB t_1O
Distance travelled in time $t_1 \to t_2$ =Area of the rectangle CD t_2t_1
Distance travelled in time $t_2 \to t_3$=Area of the rectangle EF t_3t_2

Distance travelled in time $t_6 \to t_7$=Area of the rectangle MN t_7t_6
The total distance travelled

= Area of (ABt_1 O + EFt_3 t_2
+ CDt_2 t_1 + GHt_4 t_3
...... + MN t_7 t_6)

= Total area under the graph between time 0—t_7

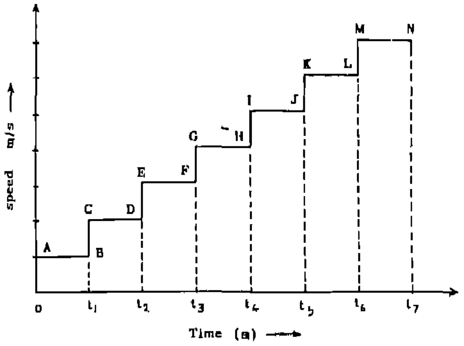


Fig. 6.20 *Computing distance travelled with a speed-time graph*

We have, therefore, shown that even if the velocity changes in the manner shown in Figure 6.20, the total distance travelled is still equal to the area under the graph.

Now just as a circle can be thought of as a polygon with an infinite number of very very small sides, a straight line can be considered to be like a staircase with a large number of very small steps This is shown in Figures 6.21a and b.

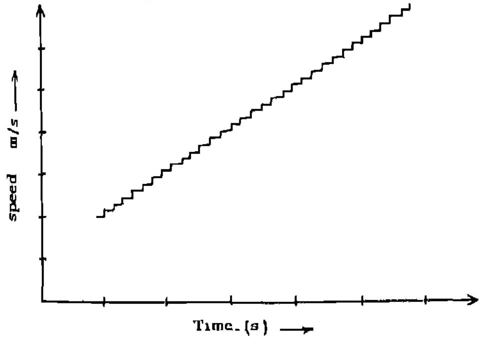


Fig 6.21a *A straight line graph may considered to be like a staircase*

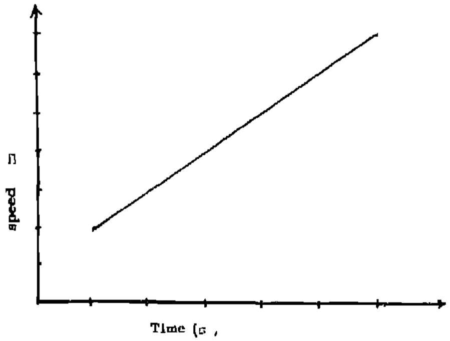


Fig 6.21 b

As the number of steps increases and the size of each step decreases, the staircase begins to resemble the straight line more and more. The result that

distance = area under the speed-time graph

has been proved for a staircase speed-time graph It must hold for a straight line also. After all, the straight line is nothing but a staircase with a very large number of steps each step being of very very small size.

Therefore, even though we cannot use the equation

distance = speed × time

for an object whose speed changes with time, we can still use the result

distance = area under the speed-time graph

We shall use this result later, to calculate the distance travelled by an object moving with uniform acceleration.

Figure 6.22 shows the speed-time graph of two cars.

Using the graph let us answer the following questions

(i) What is the acceleration of the car (a) and car (b) in the first two hours, in the next two hours and

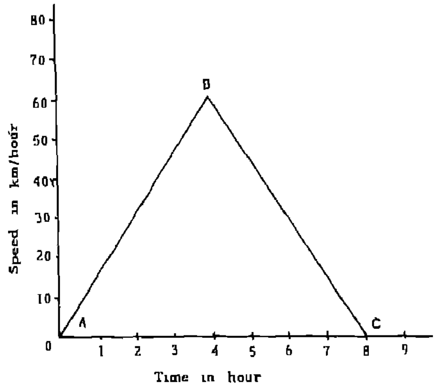


Fig 6.22a

in the last two hours?

(ii) What is the total distance travelled by the two cars?

(iii) What is the average speed of the two cars?

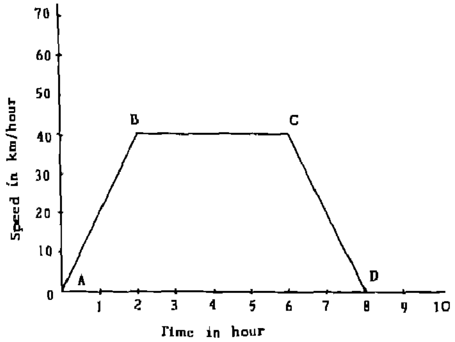


Fig. 6.22b

Notice that in the first two hours the speed-time graph of both cars is a straight line inclined to the time axis. That is, in the first two hours both cars move with uniform acceleration The speed of car (a) changes from 0 km/h to 30 km/h in 2 hours. The acceleration in the first two hours is-

$$a = \frac{\text{change in speed}}{\text{time}} = \frac{30\text{km/h}}{2\text{h}}$$
$$= 15 \text{ km/h}^2$$

The second car (b) also travels with uniform acceleration but its speed at the end of two hours = 40km/h. The acceleration is, therefore $= \frac{40\text{km/h}}{2\text{h}} = 20 \text{ km/h}^2$. In the next two hours car (a) travels with the same acceleration of 15km/h^2 but car (b) travels with zero acceleration. Notice that the speed-time graph of car (b) from time t = 2 to time t = 4 is parallel to the time axis. Its speed in this interval does not change at all

In the last two hours the speed changes from 30 km/h to 0 km/h in the case of car (a) and 40 km/h to 0 km/h for car (b)

The acceleration of car (a) is, therefore,

$$\frac{0-30}{2} = -15 \text{ km/h/h}$$
$$= -15 \text{ km/h}^2$$

and car (b) is

$$\frac{0-40}{2} = -20 \text{ km/h}^2$$

Their accelerations during this time are negative. The cars are decelerating.

Let us find the distance travelled by the two cars in the total time of 8 hours. We have proved that the distance travelled is equal to the area under the speed-time graph The area under the speed-time graph of car (a) is the area of the triangle with height 60 km and base 8 hours.

Areaof triangle = $\frac{1}{2} \times$ base $\times$ height

$$= \frac{1}{2} \times 8 \times 60 = 240$$

The distance travelled by car (a) = 240 km

For car (b) the total area under the graph is

= Area of the triangle ABM + Area of the rectangle BCNM + Area of the triangle CDN

$$= [\frac{1}{2} \times (2) \times 40] + [4 \times 40] + [\frac{1}{2} \times (2) \times 40]$$

$$= 40 + 160 + 40 = 240 \text{ km}$$

Both the cars cover a distance of 240 km in 8 hours The average speed is, therefore,

$$\frac{\text{Total distance travelled}}{\text{Total time taken}} = \frac{240}{8} = 30 \text{ km/h}$$

The maximum speed reached by car (a) which is 60 km/h is greater than the maximum speed reached by car (b) which is 40 km/h Yet the two cars travel the same distance in the same time. Who, would you say, is a safer driver?

IN THE LANGUAGE OF MATHEMATICS

Many of the equations in physics are shorthand notations where mathematics is used to express relationships between quantities. The equation is precise, concise and easy to remember. We summarise below some of the equations that we used in this chapter.

If we denote

distance = s
speed = v
acceleration = a
time = t
velocity = v
initial velocity = u
final velocity = v

$s = v.t$
$v = s/t$
$v = u + at$
$a = (v-u)/t$
$v_{average} = (u+v)/2$
$s = v_{average}\, t = 1/2\,(u+v)t$

In circular motion

arc travelled = s
radius of circle = r
angle subtended by the arc = θ (radians)

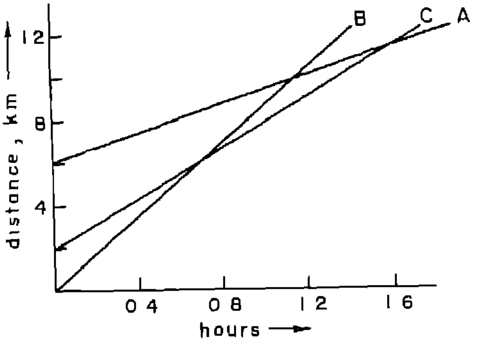
$s = r\theta$ $\qquad \theta = s/r$
$v = s/t$ $\qquad s = vt$
$r = vt$ $\qquad v/r = \theta/t$
$v = r.\omega$ $\qquad \omega$ = angular velocity in radian /second
θ in radians

QUESTIONS

1 A car travels 30 km at a uniform speed of 40 km/h and the next 30 km at a uniform speed of 20 km/h Find its average speed

2 On a 60 km track, a train travels the first 30 km at a uniform speed of 30 km/h How fast must the train travel the next 30 km so as to average 60 km/h for the entire trip?

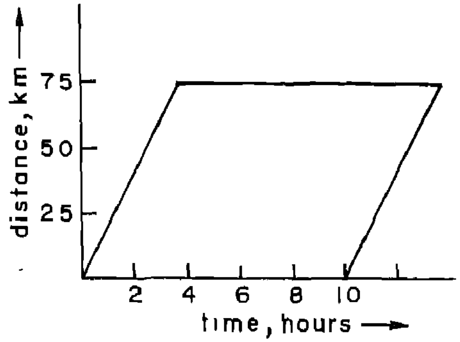
3 Figure 6 23 shows the distance-time graph of three people A, B and C. On the basis of the graph, answer the following questions



Fig, 6.23

(a) Which of the three is travelling the fastest?
(b) Are all three ever at the same point on the road?
(c) When B passes A, where is C?
(d) How far did B travel between the time he passed C and A?
(e) How far did B travel between the time he passed C and A?

4. Figure 6.24 is the distance-time graph of an object. Do you think it represents a real situation? If so, why?



Fig,6 24

5 The following is the distance time table of a moving car:

Time	*Distance*)
10.05 a.m	0 km
10.25 a.m	5 km
10.40 a.m	12 km
10.50 a.m.	22 km
11.00 a.m.	26 km
11.10 a.m.	28 km
11.25 a.m	38 km
11.40 a.m	42 km

(a) Use a graph paper and plot the distance travelled by the car versus time
(b) When was the car travelling at the greatest speed?
(c) What is the average speed of the car?
(d) What is the speed between 11.25 a.m and 11.40 a.m?
(e) During a part of the journey, the car was forced to slow down to 12 km/h. At what distance did this happen?

6. A train travels 60 km/h for 0.52 h, 30 km/h for the next 0.24 h and then 70 km/h for the next 0.71 h. What is the average speed of the train?

7. A ship is moving at a speed of 56 km/h. One second later it is moving at 58 km/h. What is its acceleration?

8. A car travelling at 20 km/h speeds up to 60 km/h in 6 seconds. What is its acceleration?

9 A driver of a car travelling at 52 km/h applies the brakes and decelerates uniformly. The car stops in 5 seconds. Another driver going at 34 km/h applies his brakes slower and stops after 10 seconds. On the same graph paper, plot the speed versus time graph for two cars. Which of the two cars travelled farther after the brakes were applied?

10. Choose the right answers in the following.

(a) In 12 minutes a car whose speed is 35 km/h travels a distance of
(1) 7 km.
(2) 3.5 km.
(3) 14 km.
(4) 28 km.

(b) When a graph of one quantity versus another results in a straight line, the quantities are
(1) both constant.
(2) equal.
(3) directly proportional.
(4) inversely proportional.

(c) A body moving along a straight line at 20 m/s undergoes an acceleration of $4 m/s^2$. After two seconds its speed will be
(1) 8 m/s.
(2) 12 m/s.
(3) 16 m/s.
(4) 28 m/s

(d) A car increases its speed from 20 km/h to 50 km/h in 10 seconds Its acceleration is

(1) 30 m/s^2.
(2) 3 m/s^2.
(3) 18 m/s^2
(4) 0.83 m/s^2

(e) A body whose speed is constant

(1) must be accelerated.
(2) might be accelerated.
(3) has a constant velocity.
(4) cannot be accelerated

(f) When the distance an object travels is directly proportional to the length of time, it is said to travel with

(1) zero velocity
(2) constant speed.
(3) constant acceleration.
(4) uniform velocity

11. What is the speed with which we blink our eyes? You have to estimate the size of the eyeball and the time the eye remains closed at each blink.

CHAPTER 7

FORCE AND ACCELERATION

INTRODUCTION

YOU HAVE LEARNT to predict the position of an object moving at uniform (constant) speed at any desired time. In our daily experiences however, we rarely deal with objects moving at uniform speed Their speeds either increase or decrease In the last chapter you learnt only to describe motion We have not yet discovered why objects move as they do Why does the speed of an object change? That is, why do bodies accelerate or decelerate? In this chapter we shall explore why objects change their speeds

7 1 Force and its Relation to Motion

Activity 1

Place a rubber ball on a flat table If you do not disturb the ball it will continue to remain where it was placed. Its speed will be zero. Its acceleration will also be zero Now give the ball a slight push It will start moving with some speed You can measure this speed if you have a ruler and a stopwatch or a watch with a seconds hand. Its speed has increased from zero, before you pushed it to this value

Activity 2

Hold the rubber ball between your palms and push your palms against each other What happens to the ball? You will notice that the ball is no longer round but oblong. Do you recall any other occasion when you exerted a force on an object to change its shape?

Activity 3

Ask your friend to roll a ball towards you. As it rolls towards you, push it in some direction (Figure 7 1) Where does the ball go? When you play cricket, do you see how a batsman flicks the ball to square leg or glances it to fine leg? Similarly, in football you can change the direction of a moving ball by kicking it Each time you do this, you have exerted a force

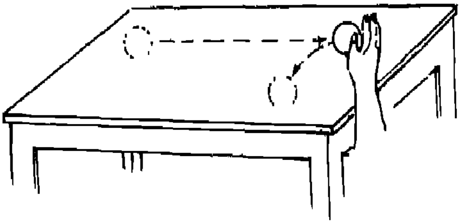


Fig 7.1

Force applied on an object can,therefore,do three things.

1. It can change the speed of the object making it move faster or slower.
2. It can change the direction of motion of the object
3. It can change the shape of the object.

Can you give examples of forces which

do any one of these three things, two of these and all three of these?

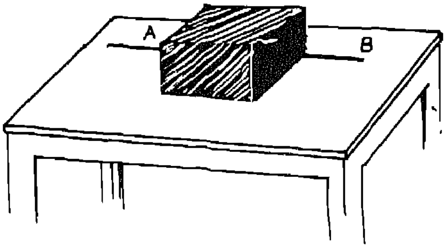


Fig. 7.2 *Two forces acting on a block*

7.2 Balanced and Unbalanced Forces

Figure 7.2 shows a block on a table. It has two strings tied to two of the opposite surfaces. If you pull at the point A the block will begin to move to the left. If you pull at B it will move to the right. But if you pull it from both the sides with equal effort, the block would hardly move. Such forces are called balanced forces. Balanced forces do not change the speed. They usually change the shape of the object on which they are applied. For example, the force exerted by your palms in Activity 2 changed the shape of the ball.

In a tug-of-war (Figure 7.3) when the two teams pull with equal effort, the rope and the two teams remain stationary. The forces exerted by the two teams in this case are balanced. Only when one of the teams pulls harder it is able to pull the weaker team towards it. In this case the forces are not balanced. It, therefore, results in the motion of the weaker team along with the rope they are holding.

We can thus say that unbalanced forces acting on an object change its speed or direction of motion.

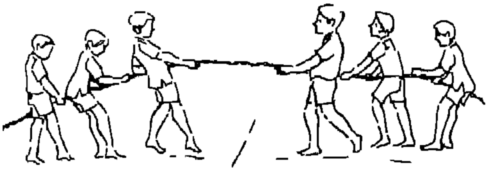


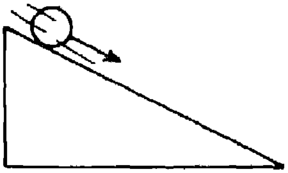
Fig. 7.3

Let us now look at the opposite situation. If the speed or the direction of motion of an object changes, are there some unbalanced forces acting on it? What happens when you ride a bicycle? When you stop pedalling, the bicycle begins to slow down. After a while you have to start pedalling again to keep it in motion. You must also have seen that a cart has to be constantly pushed to keep it in motion. These experiences tempt us to conclude that continuous application of force is necessary to maintain the motion of an object. But this conclusion is not correct. Let us see why.

What happens when we stop pedalling a bicycle? If the road is rough, it stops very soon. If the road is smooth, it keeps going longer. What would happen if the road were very smooth? Even a surface which looks very smooth is not completely so. It has small cracks and bumps which cannot be seen by the naked eye. If you look at an enlarged photograph of such a surface, it looks much like a mountainous terrain. When an object like a bicycle travels on such a surface, it has to overcome these imperfections, which slow down the object. Forces which slow down moving objects in this way are called forces of *friction*. If these forces could somehow be eliminated, an object would continue moving with the same speed. But of course, we cannot eliminate these forces entirely We can only reduce them In the game of carrom, we frequently use powder to reduce the force of friction between the coins and the wooden board. When this is done the coins travel much further than on an unpowdered board We could thus say that objects continue to move with the same velocity unless acted upon by an unbalanced force

It was Galileo who deduced that objects move with constant speed when no forces act on them. If we look around, we would hardly believe this. A coin on a table, when given a slight push, does not continue to move forever It quickly slows down and then stops. A cart on a road has to be constantly pushed to keep it in motion. A single push will not take it far. If you do not look carefully, you too, like the ancient Greeks, would be tempted to believe that objects come to rest when no forces act on them. How did Galileo come to the correct conclusion that the Greeks were wrong? Let us look at some of his observations.

He first observed the motion of objects on an inclined plane. He noted that when object move down an inclined plane, their speed increases. He also noted that when objects move up an inclined plane, their speed decreases (Figure 7.4 a and b).



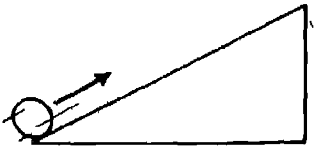


Fig. 7 4a Fig. 7.4b

He then asked the following question: What would happen if the plane were inclined neither up nor down? That is, what would happen if the ball moved on a flat surface? Well, the answer was obvious to him. Its speed would neither increase nor decrease Its speed would remain constant. He also performed another experiment But this time not with real balls and real planes but with imaginary ones. He thought that if a ball were made to fall

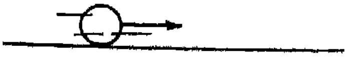


Fig. 7.5a

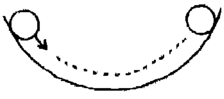


Fig. 7.5b

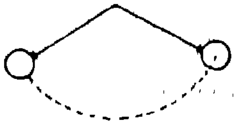


Fig. 7 5c

along the sides of hollow hemisphere it would always reach the height from which it was dropped (see Figure 7.5 b)

How did he come to this conclusion? Galileo had seen a pendulum oscillating and knew that the bob always reaches the same height The hemisphere performs the same function as the string of a pendulum in Figure 7.5c. He then asked what would happen if the vessel were shaped as in Figure 7.6a and said that it would reach the same height, but travel a longer distance in doing so.

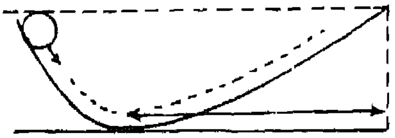


Fig 7 6 a

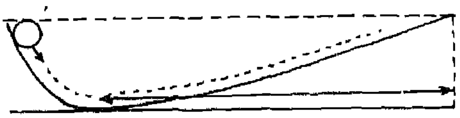


Fig. 7 6b

Notice that the more we decrease the slope at the other end of the vessel, the further the ball has to travel to reach the same height (Figure 7.6b).

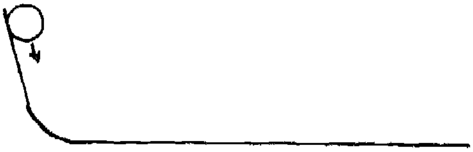


Fig. 7 6c

How far do you think the ball would travel if you decrease the slope to that of Figure 7 6c?

7.3 Newton's Laws of Motion

We have in the earlier section studied the motion of objects on which no forces act. We have seen that when no forces act on an object, its state of motion does not change That is,

1 If the object is at rest, it will continue to remain at rest.
2 If the object moves at a certain velocity, it will continue to move at the same velocity
3 Once a force is applied to the object, its velocity will change That is, it will accelerate.

These statements about the motion of objects are true anywhere in the universe. Scientists, therefore, call these statements a law This particular law is called Galileo's Law of Inertia, in honour of Galileo This law is also sometimes called *Newton's First Law*.

The statement of Galileo's Law of Inertia or Newton's First Law is just the above three statements combined in a single sentence. It states that *An object at rest or in uniform motion will remain at rest or in uniform motion unless an unbalanced force acts on it.*

In the following example try to identify the number of times the velocity of the ball changes. Also, identify the agent supplying the force in each case.

> A bowler bowls a ball at a batsman who hits it along the ground to a fielder at the fence. The fielder collects the ball and throws it back to the bowler. (Do not forget the ground which slows the ball as it moves to the fielder).

Inertia and Mass

We now know that objects continue in their state of motion when no forces act on them. This property of objects to resist any change in their motion is called inertia. The word inertia means "unchanging". It comes from the Latin word—inert. We have earlier used this word for gases like argon and neon, which do not chemically react. Let us see some more examples of this property of inertia.

Activity 4

Take an empty tumbler and place a playing card on its open end. Place a 50 paisa coin on the card. Now snap the card as shown in Figure 7.7. What happens to the coin? Why do you think the coin dropped into the tumbler?

Do you recall what happens when you are sitting in a moving bus and it suddenly stops? Or when the bus takes a sharp turn?

In all the above situations you will notice that objects prefer to maintain their state of motion. In Activity 4, the coin was at rest on the playing card. It remained at rest even when the card flew off. In the second example you and the bus were moving at the same velocity. When the bus suddenly stopped, you continued to move as before. This is what gives the effect of a jerk. In the last situation, you and the bus move with the same speed. When the bus takes a sharp turn, it changes its direction of motion. You however, tend to move in the original direction. We frequently have to hold on to support to prevent ourselves from swaying in a turning bus.

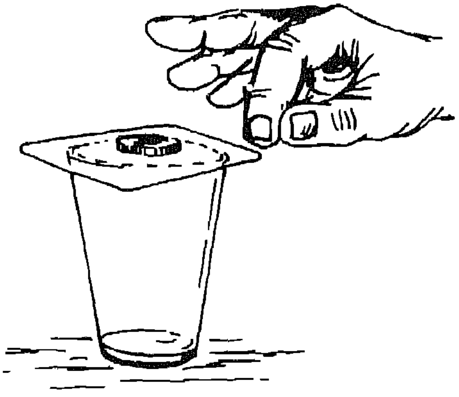


Fig 7.7a

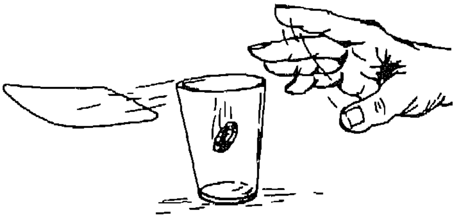


Fig 7.7b

Not all objects resist a change in their state of motion equally. Some resist more while others resist less. Instead of a 50 paisa coin, try a 5 paisa coin on the card in Activity 4. You can also perform the activity with a small pebble or a stone If you kick a football you will notice that it flies a long way. If you kick a stone of the same size, it will hardly nudge, and you may only hurt your feet The stone resists a change in its motion better than a football. That is, the stone has a greater inertia Massive objects have more inertia than lighter ones.In fact mass is a measure of inertia If a body has more mass it has more inertia

Which of the following do you think has more inertia?
(1) A football and a stone of the same size, (2) An eraser and a pencil, (3) This textbook and your school bag.

Newton's Second Law

We have seen that a force applied on an object changes the velocity of the object, that is, it accelerates the object The resistance to this change in velocity depends on the mass of the object That is, it is easier to change the velocity of lighter objects than of heavier ones.

We now know what force does, but we do not yet know how to measure it For example, if we push a ball at rest, we know that it would begin to move. But if you are asked to push the ball with twice the force as before, how hard will you push? You can never be sure what "twice the force" is, because we have not yet learnt to measure it. It is Newton's Second Law which helps you to measure force. It states that *the force on an object is proportional to the product of the mass of the object and its acceleration.*

Let us see how the second law helps us to measure force. According to it, the force acting on an object is given by,

$$\text{Force} \propto M \times a$$

Where M is the mass of the object and a its acceleration The proportionality sign ($\propto$) tells us that

$$\text{Force} = k\ M.a$$

Where k is a constant. The units of mass are gram or kilogram.The units of acceleration are cm/s^2 or m/s^2 We can choose a unit of force so that the value of k is as simple as possible.For example, we can define one unit of force as that amount which produces an acceleration of $1\ m/s^2$ in a mass of 1kg So that,

$$1 \text{ unit of force } = k\ (1kg)\ (1\ m/s^2)$$

and the value of the constant k is, therefore, 1. The force on an object is, therefore, simply equal to the product of the mass of the object and its acceleration. The unit of force is called a newton. So a force of 1 newton will produce an acceleration of $1\ m/s^2$ in an object of mass 1 kg. If you want to get a feel for a force of 1 newton, just hold a mass of 100g. The force exerted by this weight on your palm is approximately equal to 1 newton

Force = mass × acceleration ;

$$F = m\ a \qquad \text{(Equation 7 1)}$$

So now if you are asked to push an object with "twice the force" as before, you have to push hard enough so as to produce twice the acceleration as before. How will you stop a speeding ball? Will you stop it suddenly with your palm flat, or will you stop it gradually pulling your arm back with the ball? If you stop it suddenly, its velocity will decrease from a high value to zero in a very short time.Its acceleration will be very large so you will have to apply a large force, or as any *cricket player soon finds out, the ball* exerts a large force on the palm and hurts it. On the other hand, if you stop it gradually the same change in speed is brought about in a longer time. The acceleration is less than before, the force you apply, which is the same as the force the ball applies on the palm, is less too (see Figure 7.8)

Fig. 7.8

The velocity-time graph of a coin moving on a table is given in Figure 7.9. The weight of the coin is 10 gram. How much force does the table exert on the coin to bring it to rest?

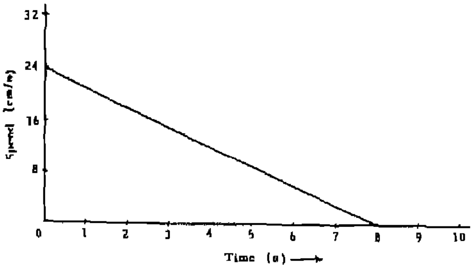


Fig. 7.9 *Velocity-time graph for motion of the coin*

Notice that the coin starts with a speed of 24 cm/s Its speed then decreases, due to the force of friction exerted by the table. It comes to rest after eight seconds

$$\therefore v_{\text{initial}} = 24 \text{ cm/s}$$
$$v_{\text{final}} = 0 \text{ cm/s}$$

It moves with constant acceleration. (Remember that when the acceleration is constant, the velocity-time graph is a straight line.)

Its acceleration is, therefore,

$$a = \frac{v_{\text{final}} - v_{\text{initial}}}{\text{time taken to change}}$$
$$= \frac{0-24}{8} = -3 \text{ cm/s}^2 = -0.03 \text{ m/s}^2$$

The force exerted on the coin is, therefore,

$$m \times a$$
$$= (-0.03) \times (0.01) \text{ kg m/s}^2$$
$$= -0.003 \text{ newton}$$

The negative sign tells us that the force exerted is opposite to the direction of motion.

Let us now try and answer another important question How far does the coin travel before it comes to rest? This question is difficult to answer for general forces But if the object is acted upon by a constant force, the answer is quite simple.

Distance-Time Relation for Uniform Acceleration

When a constant force acts on a body, the acceleration of the body does not change The body moves with uniform acceleration and the speed-time graph is a straight line as in Figure 7 10. We now want the relation between the position of such an accelerating body and time.

We want to find the distance travelled from time t_1 to time t_2 As we saw in the earlier chapter, this distance is just the

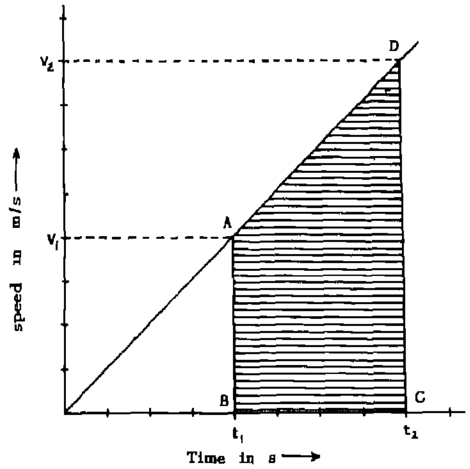


Fig 7.10 *Speed - time graph*

area under the speed-time graph between these two times which is the area of trapezium ABCD.

$$\text{Distance travelled} = 1/2\ (AB + CD) \times BC$$

$$= 1/2\,(v_1 + v_2)\,(t_2 - t_1) \quad \text{(Equation 7 2)}$$

Since the acceleration of the body is 'a' we have

$$a = \frac{v_2 - v_1}{t_2 - t_1} \quad \text{(Equation 7 3)}$$

So that

$$v_2 = v_1 + a(t_2 - t_1) \quad \text{(Equation 7 4)}$$

We can now use this v in Equation 7 2 to give

$$\text{Distance travelled} = v_1(t_2 - t_1) + \frac{1}{2}\,a\,(t_2 - t_1)^2$$

In general, if the initial velocity is denoted as u, the final velocity as v, acceleration as a, and the time interval as t, then the distance travelled s is written as

$$s = ut + \frac{1}{2}\,at^2 \quad \text{(Equation 7 5)}$$

If we know the initial speed and the uniform acceleration we can find the distance travelled by the body in any time

In the case of the coin the initial velocity is 24 cm/s and the acceleration is -3 cm/s^2. If we want to find the distance travelled by the coin before it stops, we must take

$v_1 = 24$ cm/s, $t_1 = 0$ and $t_2 = 8$ s

$$\text{Distance travelled} = 24 \times 8 + \frac{1}{2}(-3)\,(8 \times 8)$$

$$= 96 \text{ cm}$$

Remember you can use this expression only if the body moves with uniform acceleration, that is, when the force acting on the body does not change with time

7.4 Momentum

We have seen that when a force is applied to an object it is accelerated The acceleration produced is related to the force applied by Newton's second law of motion

$$F = ma \quad \text{(Equation 7.1)}$$

That is, if the velocity of the object changes from v_1 m/s to v_2 m/s in t seconds, then

$$F = \frac{m\,(v_2 - v_1)}{t} = \frac{mv_2 - mv_1}{t}$$

The quantity mv_1 or mv_2 that appear in the above equation is called the *momentum* of the object

The momentum of an object is the product of its mass and velocity, and is denoted by p.

$$p = mv \quad \text{(Equation 7 6)}$$

The second law of motion can, therefore, also be written as

$$F = \frac{p_2 - p_1}{t} \quad \text{(Equation 7.7)}$$

That is, force on a body is the change of momentum per unit time.Since the momentum of a body is the product of its mass and its velocity, the momentum of a truck moving at 10 km/h is more than the momentum of a small marble moving with the same speed. If both are brought to rest, the change in the momentum of the truck would be much more than that of the marble It is not surprising,therefore,that it requires more force to stop a truck than to stop a marble moving with the same speed

7.5 Friction

We have seen how the force of friction slows down moving objects This force can be reduced by smoothening the small bumps and cracks which impede motion However, the force of friction cannot be eliminated. We have seen how a small quantity of powder on a carrom board can fill up these bumps and cracks A coin on a powdered carrom board,therefore,travels much farther than on an unpowdered board. A solution of soap and water or oil can also reduce the force of friction between two surfaces considerably

The force of friction is not always a disadvantage It is this force which prevents us from slipping when we walk on the road. If this force were absent we would hardly be able to get a grip on the road Is it not difficult to stop the motion of your foot when it accidentally steps on a banana leaf? You may have had a similar difficulty while walking on a road with a lot of green algae during monsoon The force of friction in these situations is considerably reduced

The tyres of vehicles are always made rough in order to increase the force of friction Smooth tyres or oily roads can make the motion of the vehicle uncontrollable and lead to accidents A reduction in the force of friction can also lead to other problems For example,the force of friction in liquids is much smaller than between two solid surfaces A ship encounters a much smaller frictional force from the water To stop a moving ship, therefore takes much more time and needs a larger force than to stop a moving car on the road

The two laws of motion tell us how an applied force changes the motion of objects There is yet another law which tells us something more about the applied forces themselves The law is called Newton's Third Law The effects explained by the third law are so familiar to us in our daily life that we may miss the importance of this law, if we do not observe carefully.

Newton's Third Law states that:

> *In an interaction between two bodies the force exerted by the first body on the second is equal and opposite to that exerted by the second body on the first body;*

or action and reaction are equal and opposite.

To understand the law, let us first explore the meaning of the word—interaction When one object influences another object by the application of a force we say that the first body has interacted with the second. For example, when two marbles collide and change each other's path, they have interacted with each other Similarly, when a magnet attracts a piece of iron, the two are interacting

The kicking of a football and the collision between marbles are examples of interaction where the two interacting objects are in contact. But for an interaction, that is, for one object to influence another by a force, the objects need not always be in contact For example, the magnet exerts a force on the iron piece even when they are separated by a distance There are other examples of such interactions that take place at a distance Two magnets exert a force on each other, or an electrically charged comb attracts bits of paper from a distance The earth pulls a stone released from a height towards it

Newton's Third Law describes the relationship between the forces that come into play when two objects interact with one another Let us observe the interaction between two marbles.

Figure 7 11 shows two marbles approaching each other. The directions of their motion are shown by the arrows on each of them Let us see what happens after they have interacted, that is, after they have collided

After collision the two marbles change their direction of motion According to the Law of inertia, we must now find the force which caused this change in the direction of motion In fact we must look for two forces, one that accelerated (i e changed the direction of motion) marble A, and one that accelerated marble B This is true of any interaction In any interaction there are always two forces that come into play When a magnet and a piece of iron are brought close to each other there are two forces in play One is the force with which the magnet attracts the iron piece and the second is the one with which the iron attracts the magnet A ball thrown up ultimately accelerates and falls down The force responsible for the acceleration of the ball as it returns to the earth is the force of gravity which the earth exerts on the ball While the earth pulls the ball, the ball also pulls the earth towards itself We shall study this force in detail in the next chapter

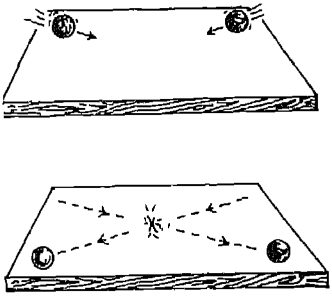


Fig 7.11 *Interaction of two balls*

A PROBLEM TO PONDER

We have derived the relation between the distance travelled by a uniformly accelerated object and time If motion starts at time $t = 0$, we have shown that

$$\text{distance travelled} = s = ut + \frac{1}{2}at^2 \qquad \text{(Equation 7 5)}$$

Where u is the initial velocity and a the uniform acceleration of the object. If the object starts from rest, that is, its initial velocity $u = 0$ this relation reduces to

$$\text{distance travelled} = s = \frac{1}{2}at^2$$

What would be the distance-time graph of this object look like in the following cases

(i) $a = 2\ \text{m/s}^2$; and (ii) $a = 8\ \text{m/s}^2$?

To plot a graph of this relation, let us first make a table of distance and time in the two cases and then plot the graphs of these two tables as Figures 7 12 and 7 13.

a 2m/s^2		$a = 8\text{m/s}^2$	
time (seconds)	distance (metre)	time (seconds)	distance (metre)
0	0	0	0
1	1	1	4
2	4	2	16
3	9	3	36
4	16	4	64
5	25	5	100
6	36	6	144
7	49	7	196
8	64	8	256
9	81	9	324
10	100	10	400

$s = t$ $s = 4t$

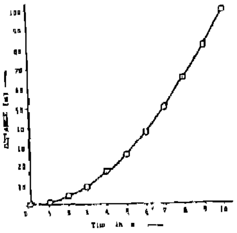


Fig. 7.12

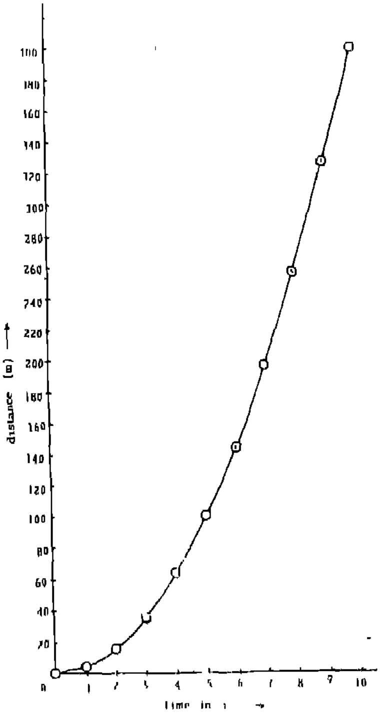


Fig 7 13 (

The shape of the curve we obtained is called a parabola. In fact it was Galileo who first deduced that if an object travels with uniform acceleration, the distance travelled varies as the square of the time taken Galileo did not have good clocks to measure time, accurately. But that did not discourage him He used a vessel full of water with a small hole at the bottom. Water from this vessel would drip from the hole continuously. The amount of dripping water that he collected would tell him how much time had elapsed It is also said that he used his pulse to measure the period of a swinging pendulum.

IN THE LANGUAGE OF MATHEMATICS

If we denote

distance = s

mass = m

acceleration = a

time = t

velocity = v

force = f

momentum = p

$p = mv$ $v = u + at$ $f = ma$

$f = \frac{p_2 - p_1}{t_2 - t_1}$ Impulse of force = f t

$s = ut + \frac{1}{2} at^2$ $2as = v^2 - u^2$

QUESTIONS

Choose the right answer in the following questions

1 When an object undergoes acceleration
  - (a) its speed always increases
  - (b) its velocity always increases
  - (c) it always falls towards the earth
  - (d) a force always acts on it.

2. A force acts on an object which is free to move. If we know the magnitude of the force and the mass of the object, Newton's second law of motion enables us to determine the object's
  - (a) weight.
  - (b) speed
  - (c) acceleration.
  - (d) position

3 When a force of 1 newton acts on a mass of 1 kg that is able to move freely, the object moves with a
  - (a) speed on 1 m/s
  - (b) speed of 1 km/s.
  - (c) acceleration of 10 m/s^2
  - (d) acceleration of 1 m/s^2.

4 When a net force acts on an object, the object will be accelerated in the direction of the force with an acceleration proportional to
  - (a) the force on the object.
  - (b) the velocity of the object
  - (c) the mass of the object.
  - (d) the inertia of the object

5 If A and B are two objects with masses 6 kg and 34 kg respectively, then
  - (a) A has more inertia than B.
  - (b) B has more inertia than A.
  - (c) A and B have the same inertia
  - (d) none of the two has inertia

6 The action and reaction forces referred to in Newton's third law
  - (a) must act on the same object.
  - (b). may act on different objects
  - (c) must act on different objects
  - (d) need not be equal in magnitude but must have the same direction

7 Why do the passenger in a bus tend to fall backward when it starts suddenly?

8 Which would require a greater force—accelerating a 10 g mass at 5 m/s^2 or a 20 g mass at 2 m/s^2?

9 What is the acceleration produced by a force of 12 newton exerted on an object of mass 3 kg?

10 What force would be needed to produce an acceleration of 4 m/s^2 on a ball of mass 6 kg?

11 An object undergoes an acceleration of 8 m/s^2 starting from rest Find the distance travelled in one second

12. A truck starts from rest and rolls down a hill with constant acceleration It travels a distance of 400 m in 20s Find its acceleration. Find the force acting on it if its mass is 7 metric tonnes

13 A certain force exerted for 1.2 s raises the speed of an object from 1.8 m/s to 4.2 m/s. Later this same force is applied for 2 s How much does the speed change in 2 s?

14 Two blocks made of different metals identical in shape and size are acted upon by equal forces which cause them to slide on a horizontal surface The acceleration of the second block is found to be 5 times that of the first, what is the ratio of the mass of the second to the first?

15 A force of 5 newton gives a mass m_1 an acceleration of 8 m/s^2 and a mass m_2 an acceleration of 24 m/s^2 What acceleration would it give if both the masses are tied together?

16 The following is the distance-time table of an object in motion

Time in seconds	*Distance in metre*
0	0
1	1
2	8
3	27
4	64
5	125
6	216
7	343

(a) What conclusion can you draw about the acceleration? Is it constant? Increasing? Decreasing? or Zero?

(b) What do you infer about the forces acting on the object?

GRAVITATION

INTRODUCTION

AN OBJECT changes its speed or direction of motion only when a force is applied on it. We need to identify forces which accelerate objects We have done one such exercise on the cricket field Each time we saw the ball changing its velocity, we could detect the force responsible for it Either the force was applied by the bowler's arm, the batsman's bat or the force was exerted by the ground which changed its motion.

Activity 1

Hold a small stone in your hand. Just release it without pushing. Observe the motion of the stone. Can you now answer the following questions?

1. What was the speed of the stone when you held it in your hand?
2. Did it have the same speed just before it hit the ground?
3. Did the stone accelerate?

We must now identify the force which accelerated the stone You certainly did not push the stone Then how did it accelerate? It was Issac Newton who posed this question and answered it. Newton stated that all objects attract each other along the line joining their centres.

The earth and the stone also attract each other. To begin with you held the stone in your hand and did not allow it to move (is that why the stone feels heavy?). When released it moved towards the earth, in fact accelerated towards the earth, until it hit the ground (Figure 8.1).

Not only the stone but every object in the universe attracts every other object towards itself. Even the falling stone attracts the earth If the earth had not attracted the stone it would have remained suspended in the air after you withdrew your support.

This force with which two objects attract each other is called the force of gravitation This force of gravitation acts even if there is nothing connecting the two objects

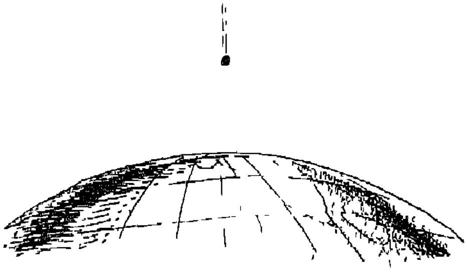


Fig. 8 1 *A stone falling towards earth*

8.1 The Universal Law of Gravitation

Newton did not stop after proposing that a force of gravitation exists. He expressed the law in a clear and precise language—the language of mathematics This law is called the Universal Law of Gravitation It states that:

Any two point particles with masses m_1 and m_2 attract each other by a force whose magnitude is directly proportional to the product of the two masses, that is to m_1m_2 and inversely proportional to the square of the distance between them. The direction of the force is along the line joining the two masses

If we denote the distance between two masses by R , the law of gravitation states.

$$F \propto \frac{m_1 \times m_2}{R^2}$$

where F denotes force with which the two masses attract one another. The proportionality sign means that

$$F = G\frac{m_1 \times m_2}{R^2} \qquad \text{(Equation 8.1)}$$

where G is a constant G does not depend on the value of m_1, m_2 or R. It also does not depend on who measures F and when or where it is measured.

The constant G will remain the same for any two objects. We can measure the force of attraction between the sun and the earth or a stone and earth, or between two distant stars. The ratio

$$F\Big/\left(\frac{m_1m_2}{R^2}\right)$$

which is equal to the constant G, is the same for any of these pairs of objects

Such constants are called universal constants They are very special numbers This particular constant—G, is extremely small. However, scientists have performed very careful experiments to measure G. They took two heavy gold balls and hung them next to each other with strong but delicate threads. They then measured the force between these balls Repeating the experiment, carefully, several times they found the numerical value of G.

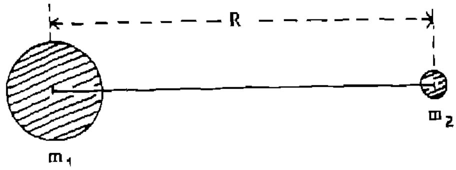


Fig. 8.2 *Set-up of the experiment to determine value of G*

What will be the units of G? G is a ratio of the force F and the product $\frac{m_1m_2}{R^2}$ · Its units, therefore, depend on the units in which force, mass and distance are measured If mass is measured in kg, distance in metres and time in seconds, then the unit of force is newton The units of G will, therefore, be

$$\text{newton } m^2/(kg)^2 = N.m^2/kg^2$$

The experiment with gold balls gave the value of G to be

$$0.000000000066734$$
$$= 6.6734 \times 10^{-11}\ N.m^2/kg^2$$

We can now see that G in these units is a very, very small number.

Gravitational Force between Objects of Ordinary Size

Let us see how weak the force of attraction between ordinary objects is Can you find the force with which you and your friend sitting on the next bench attract each other? This is very easy to calculate, just use the law of gravitation -(Equation 8.1)

F= Force of attraction

$$= \frac{6.6734 \times 10^{-11} \times m_1 \times m_2}{R^2}$$

If you and your friend have the same mass of 35 kg and are separated by 1 metre, the force of attraction would be

$$F = \frac{6.6734 \times 10^{-11} \times 35 \times 35}{1 \times 1}$$

$$= 0.00000008175 \text{ newton}$$
$$= 8.175 \times 10^{-8} \text{N}$$

This force is at least a hundred times weaker than the force exerted by a small speck of paper (about 0.1 mg) on the pan of a balance

You can also see how weak the force of gravitation is when you lift an ordinary sized stone or when a magnet picks up a common pin. The gravitational attraction between these objects and the earth is so easily overcome.

However, if the two objects or even one of the objects has large mass, the force becomes appreciably stronger. Let us find the force of attraction between you and the earth, when you are on its surface. The mass of the earth is about 6×10^{24} kg and the distance separating you from the centre of the earth is the radius of the earth which is 6.37×10^6m. If you take your mass to be about 35 kg the force of attraction will be

$$\frac{6.6734 \times 10^{-11} \times 35 \times 6 \times 10^{24}}{6.37 \times 10^6 \times 6.37 \times 10^6} = 345.4 \text{N}$$

The force with which you and the earth attract each other is almost a thousand million times stronger than the force of attraction between you and your friend sitting next to you We can ignore the force between you and your neighbour, but we certainly cannot ignore the force between you and the earth. When we deal with the earth, or the moon or the sun, we are dealing with objects with very large masses like 10^{24} kg, gravitational force between such huge objects is , therefore, quite large.

8.2 Newton's Third Law and Gravitation

We know from Newton's third law that if an object A exerts a force on another object B, then B exerts an equal force on A in the opposite direction. This is true of the force of gravitation also. For example, we had observed earlier that a stone when dropped accelerates and falls towards the earth This is due to the gravitational force exerted by the earth on the stone. In fact, the stone also attracts the earth with an equal force Why then, do we see the stone falling to the earth, but not the earth rising towards the stone?

It is true that the gravitational pull of the stone on the earth is equal to the pull of the earth on the stone However, the acceleration produced in the stone and in the earth are not equal. Let us find the force exerted by the earth on the stone. Let us take a stone weighing 1 kg. The mass of the earth is 6×10^{24} kg If the stone and the earth are separated by 6.4×10^6 m,the force of attraction is

$$F = \frac{6.6734 \times 10^{-11} \times 1 \times 6 \times 10^{24}}{6.4 \times 6.4 \times 10^{12}}$$

$$= 9.8 \text{ newton}$$

We can now use Newton's second law to find the acceleration a of the stone as it falls to the earth.

$$a = \frac{F}{m} = 9.8 \text{ m/s}^2$$

The stone also pulls the earth with a force of 9.8 newton. The acceleration of the earth due to this pull can also be calculated from the second law.

$$a_{earth} = \frac{F}{M_{earth}}$$

$$= 0.00000000000000000000000165 \text{ m/s}^2$$

$$= 1.65 \times 10^{-24} \text{ m/s}^2$$

Compared to the acceleration of the stone which is 9.8 m/s^2 this is very very small; so small that you do not see the earth rise at all. What would happen if the two objects had comparable masses? Then their acceleration would also be comparable and you would see the two objects moving towards each other.

In fact there are two such objects in the sky. Two stars, Sirius and its companion move around each other because their masses are comparable. Sirius can be seen in the sky but its companion, though massive, is very small and cannot be seen.

8.3 Falling Objects

In the earlier section, we had observed a falling stone. We noticed that the speed of the stone increased as it fell to the earth. We said that this acceleration was due to the force of attraction between the stone and the earth. Can we measure this acceleration? Will this acceleration be large if the body has a large mass? Will heavier objects accelerate more than lighter ones?

If you drop a small pebble and a ball of cotton of the same size, you will notice that the pebble falls to the ground much before the cotton ball does. You would be tempted to conclude that heavier objects fall faster than lighter ones.

In fact, this was the common belief for quite a long time. It was Galileo who decided to test the common feeling experimentally. There is a legend that he dropped two stones of different masses from the top of the Leaning Tower of Pisa. He concluded that the acceleration of an object falling freely towards the earth does not depend on the mass of the object.

Galileo attributed the slowing down of lighter bodies to the resistance or the friction offered by air. If there were no air, he said, two objects of different masses would reach the ground together when dropped from the same height. Though Galileo could not show this experimentally, the British scientist Robert Boyle used a vaccum pump to remove air from a tube containing a heavy coin and a scrap of paper. When the tube was inverted, both, the coin and the paper hit the bottom at the same time. Just as Galileo had predicted.

Using the universal law of gravitation, we can easily check if Galileo's assertion was true.

If we drop a stone of mass m from a distance of R from the centre of the earth, the earth exerts a force given by

$$F = \frac{GM_e}{R^2}$$

In the equation M_e denotes the mass of the earth and G the gravitational constant. The acceleration of the stone is, therefore,

$$\text{Acceleration} = \frac{F}{m}$$

$$= G\frac{M_e}{R^2} \text{ (Equation 8.2)}$$

Notice that this acceleration does not depend on the mass m that is dropped. It only depends on the mass of the earth and the height of the object from the centre of the earth. This acceleration is called the acceleration due to gravity. Since it is the same for all freely falling objects, it is denoted by a special symbol—'g'

$$g = G\frac{M_e}{R^2} \qquad \text{(Equation 8.3)}$$

In the next chapter on the simple pendulum, you will learn to find g by doing a very simple experiment. Now, if we substitute the values of the mass of the earth and, its radius in the above equation, we can get the numerical value of this acceleration

$$g = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^6)^2}$$

$$g = 9.8 \text{ m/s}^2$$

Now that we have found the acceleration of freely falling objects on earth, we can find the speed and the distance travelled by these objects in a given amount of time. We can use the relations derived earlier for constant acceleration in Chapter 7.

speed after time t $v = u + at$

distance travelled in time t, $s = ut + \frac{1}{2}gt^2$

Where u is the initial speed, v the final speed and g the acceleration due to gravity. If the object is released with zero speed that is $u = 0$, these relations become

speed after time t second $= gt$

distance travelled in time t $= \frac{1}{2}gt^2$

We can now predict the motion of objects dropped from a height. What would be the motion of an object thrown up? Remember the force of gravity does not depend on the velocity of the object It depends only on the distance separating the two objects and their masses The earth continues to attract bodies thrown up also. But since the direction of the force of gravity on an object thrown up is opposite to the direction of motion, the object is initially slowed down. Just like a coin moving on a flat table which is slowed down due to the force of friction The acceleration of a body thrown up will be numerically the same as the acceleration of falling body, but opposite in sign.

Acceleration due to gravity of a body thrown up $= -9.8 \text{ m/s}^2$

The velocity of an object thrown up would, therefore, decrease at the rate of 9 8 m/s. The velocity decreases until it reaches zero It then falls back to the earth as any object thrown from that height.

Let us do an exercise. A ball is dropped from a height of 1 metre How long does it take for the ball to reach the ground. With what speed does it hit the ground?

The ball is dropped with an initial speed of zero and we use the relation found above to obtain the time taken to travel 1 m and the final speed so that

$$1\ \mathrm{m}\ \frac{1}{2}(9.8)\times t^2$$

which gives $t=\sqrt{\frac{2}{9.8}}\ \mathrm{s}=0.45\ \mathrm{s}$

Once we know the time taken, we can easily find the final speed from the relation.

$$v=gt=9.8\times 0.45=4.4\ \mathrm{m/s}.$$

A ball is thrown up with a speed of 0.5 m/s. How high will it go before it begins to fall?

The initial speed of the ball is 0.5 m/s. Since the ball travels with an acceleration of $-9.8\ \mathrm{m/s^2}$, we have to find the time taken for its speed to decrease to 0 m/s. We shall use the relation

$$v=u+gt$$

with $v=0$, $u=0.5\ \mathrm{m/s}$ and $g=-9.8\ \mathrm{m/s^2}$. The time taken is, therefore,

$$0.5=9.8\,t$$

$$\therefore\ t=\frac{0.5}{9.8}\simeq 0.05\ \mathrm{s}.$$

The distance travelled in this time is

$$\text{distance}=ut+\frac{1}{2}gt^2$$

$$\simeq 0.5\times(0.05)-\frac{1}{2}(9.8)\times(0.05)\times(0.05)$$

$$\simeq 0.025-0.0122\simeq 0.013\ \mathrm{m}$$

$$=1.3\ \mathrm{cm}$$

8.4 Measuring Mass with Gravity

When we studied Newton's Second Law of Motion, we compared masses rather crudely. Since our basis of comparison was the volume of the bodies, we could only compare objects of the same kind. The force of gravity, because it depends on the masses, gives us a good method of comparing masses. If the earth attracts two objects with equal force, what can you say about their masses? Let us consider two objects with masses m_1 and m_2. Let us hold them at the same distance from the centre of the earth. The force of attraction between m_1 and the earth is

$$F_1=G\frac{M_e m_1}{R^2}$$

The force of attraction between the earth and m_2 is

$$F_2=G\frac{M_e m_2}{R^2}$$

If we find that the forces acting on these two masses are equal then the masses of the two objects should also be equal. That is

if $F_1=F_2$
then $m_1=m_2$

Therefore, if by some method we could check whether the forces are equal we would have a method for comparing masses. A pan balance does precisely this. When the objects in the two pans of a pan balance are such that the two pans remain stationary at the same height we know that the force of attraction on the two masses is equal. If this were not so, then the two pans would not balance and stay at the same height.

We have now a method of comparing the masses of two objects by a pan balance. We can now by common agreement decide on a standard mass, and compare the masses of other objects with this standard. In fact we have all agreed on 1kg as the standard quite arbitrarily and have placed that standard in important places in the world.

Weight

Now that we know how to measure the masses of ordinary objects, using a simple pan balance, we can calculate the force with which the earth attracts these objects This force is called the weight of the object on earth or simply *"weight."* On earth, the weight of an object is just the force between the object and the earth The weight of the same object will be different in different parts of the universe. For example, the weight of an object on the moon is the force with which the moon attracts that object. It will be different from the weight on earth since the mass of the moon and its radius are not the same as the mass and the radius of the earth. In fact the weight of an object on the moon is 1/6th its weight on earth.

Let us see where number 1/6 comes from. Let the *mass* of the object be m Its *weight* on earth, that is, the force with which the earth attracts this mass is given by

$$F_e = G\,\frac{M_e m}{R_e^2}$$

Where M_e, is the mass of the earth, R_e its radius, and G the gravitational constant.

When this object is on the moon, its weight will be

$$F_m = G\,\frac{M_m . m}{R_m^2}$$

Where M_m and R_m are the mass and the radius of the moon The ratio of its weight on the moon to its weight on earth will,therefore,be

$$\frac{F_m}{F_e} = \frac{M_m}{M_e} \times \left(\frac{R_e}{R_m}\right)^2$$

Now, the mass of the earth is about 100 times the mass of the moon and its radius is 4 times that of the moon Substituting these values in the equation above we get

$$\frac{F_m}{F_e} = \frac{1}{100} \times (4)^2 = \frac{16}{100} \simeq \frac{1}{6}$$

The mass of the object is the same m, on earth and on the moon.But its weight on earth is about six times greater than its weight on the moon

"WEIGHTLESSNESS" IN SPACE

We often hear that an astronaut in deep sapce is weightless. What does this really mean. Let us find the force with which the earth attracts him when he is at a distance of 12,800 km from the centre of the earth This distance is twice the radius of the earth. Remember the force of attraction decreases as the square of the distance

The force therefore,will be 1/4 times the force of attraction when he is on earth That is, his weight at a distance of 12,800 km will be 1/4th his weight on earth, but certainly not zero Why then, do we say he is weightless?

We usually measure our weight by standing on a weighing machine which rests on the floor.If this floor were to be suddenly removed both you and the scale would fall towards the earth with the same acceleration It is then no longer possible for you to exert a force on the scale since the earth pulls the scale just as rapidly as it pulls you The scale would in this case show a zero weight.

It is in this sense that the astronaut is "weightless" The space vehicle, with the astronaut and the scale all fall towards the earth with the same acceleration. He,therefore,does not exert any force on the scale or the sides of the vehicle and therefore,appears to be floating "weightlessly"

You can check this by holding a heavy object at the end of a spring balance.The spring will show the weight of the object Now release the spring balance and read the "weight" as it falls.You will find that the weight shown by the balance will be zero. Will you conclude that the object is truly weightless? See Figures 8 3. a and b.

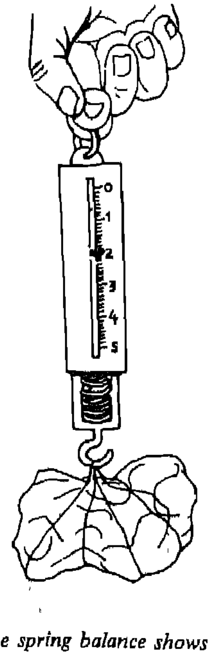


Fig. 8.3a *The spring balance shows the weight of the stone*

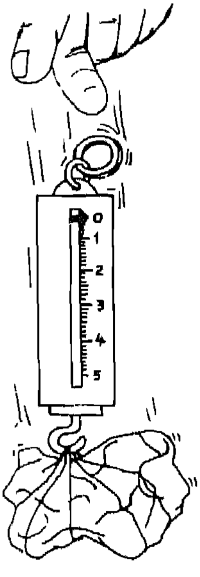


Fig. 8.3b *Freely falling spring balance with the stone shows a zero reading*

8.5 Projectiles and Planets

We have studied the motion of an object like the stone accelerating towards the earth. When released with zero velocity, it will travel a distance d given by

$$d = \frac{1}{2} gt^2$$

in time t. In the expression 'g' denotes the acceleration due to gravity on the surface of the earth.

What will happen if the stone was thrown parallel to the surface of the earth? It is our common observation that the trajectory of the stone will be as shown in Figure 8.4 by the thick curve.

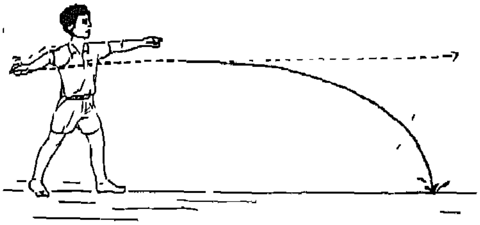


Fig 8.4 *Trajectory of a stone thrown horizontally*

If the gravitational attraction of the earth were absent the stone would continue to move in the horizontal direction shown by the dotted line since no force acts on it. This is because of its inertia. However, due to the attraction of the earth, the stone changes its direction of motion (accelerates) and falls some distance away from the thrower. Let us perform some experiments to discover more about this motion.

Activity 2

Take two coins and place them next to each other on the edge of a table. Now flick away one of the coins parallel to the ground and release the second so that it just topples over (Figure 8.5a). Take care to ensure that both coins leave the table at the same time. Do the two coins hit the ground simultaneously? You can decide this by listening to the clink of the coins as they reach the ground. If you hear only one clink you can conclude that they hit the ground simultaneously. If you hear two distinct clinks, you can be sure that the coins reach the ground at different times.

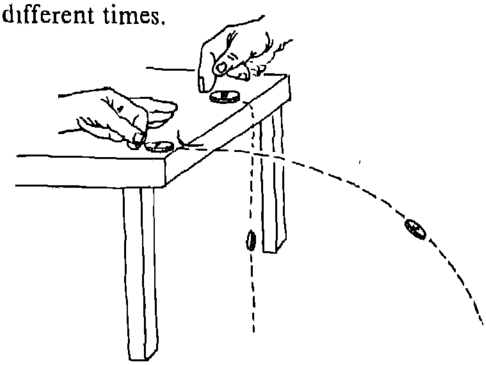


Fig. 8.5a

If you perform this activity carefully, you will notice that both coins take the same amount of time to travel the vertical distance from the table to the ground. You can try this activity by flicking one of the coins with different speeds or from tables of different heights. As long as your flick is parallel to the surface and both coins leave the edge of the table simultaneously, the coins will hit the ground at the same time.

This shows that in any given time interval, the vertical distance travelled by an object thrown parallel to the surface of the earth is the same as that travelled by an object released from the same height. Figure 8.5b shows this fact pictorially. Notice how both coins are at the same height at any given time.

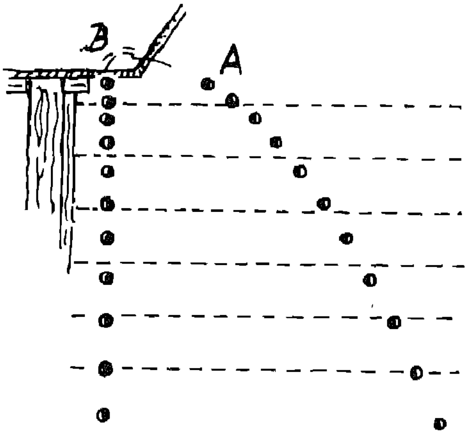


Fig 8.5b

The relation between the vertical distance travelled and time taken for object A in Figure 8 5b will therefore, be the same as the relation for object B

Vertical distance travelled by a projectile thrown parallel to the ground in time t $= \frac{1}{2} gt^2$.

The horizontal distance travelled by such objects will, however, be different This horizontal distance will depend on the speed with which it was initially thrown The larger the speed with which these are thrown, the larger is the horizontal distance travelled Figure 8 6 shows the trajectories of objects thrown parallel to the ground with different speeds Notice how the horizontal distance covered increases as the throwing speed ncreases

Such falling objects are called projec-s (that is, those which are projected or rown).

Now remember that the earth is a sphere As the trajectory of these projec-

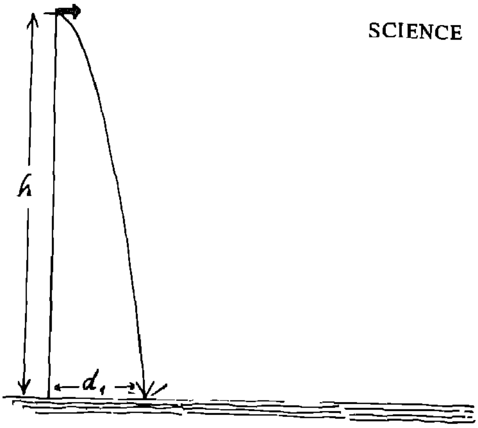


Fig 8 6a

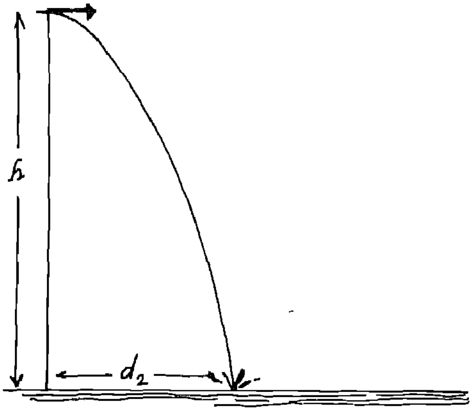


Fig.8 6b

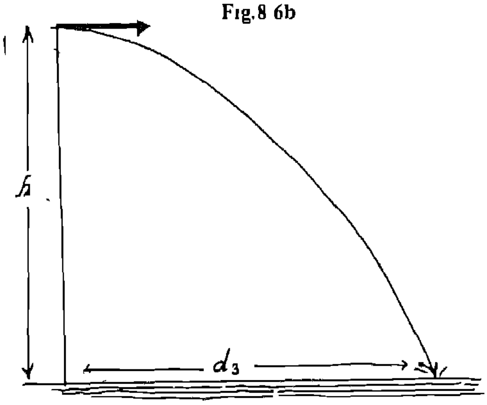


Fig 8 6a,b,c *The horizontal distance travelled by a projectile increases with initial speed* tiles curves towards the earth, the surface of the earth also curves away from under it Therefore, it is possible to throw a projectile with such a high speed that it continues to fall but never reaches the ground. In every time interval the object falls through some vertical distance, but it misses the earth since the surface of the earth curves away from it Such a projectile will travel around the earth repeatedly. That is, it will keep orbiting the earth Newton realised that the moon orbiting the earth could be such a projectile. It has just the right speed to keep circling the earth. It completes one such circle in 27 days and 8 hours.

The vertical distance that the moon falls through in 2 days can be easily calculated. The force with which the earth pulls the moon is given by

$$F = G\frac{M_e M_m}{R^2}$$

Where M_e is the mass of the earth, M_m the mass of the moon and R the distance from the earth to the moon.

Its acceleration by Newton's Second Law will be

$$a = \frac{F}{M_m} = \frac{GM_e}{R^2}$$

Since all falling objects travel a vertical distance given by the same relation

$$\text{vertical distance} = \frac{1}{2}at^2$$

In 2 days, therefore, the moon falls a distance of

$$\text{vertical distance} = \frac{1}{2}a\,(24\times24\times3600\times3600)\times4$$

Astronomers have found that the distance (R) from the earth to the moon is 60 times the radius of the earth (R_e)

Using this information that

$$R = 60\,R_e$$

We get the vertical distance travelled in 2 days

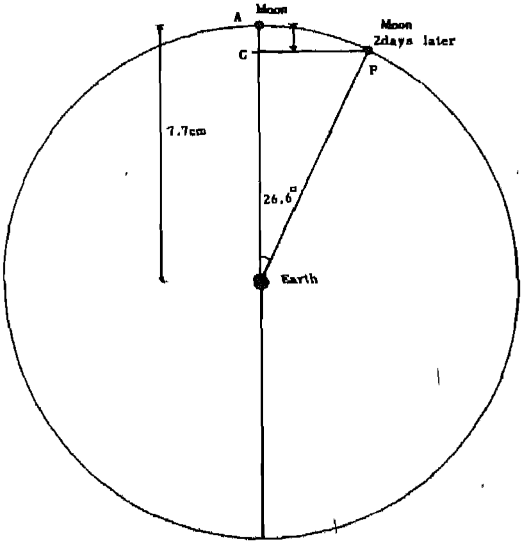
$$= \frac{1}{2}\,\frac{GM_e}{60\times60\times R_e^2}\times48\times48\times3600\times3600$$

$$= \frac{1}{2}\times\frac{1}{3600}\left(\frac{GM_e}{R_e^2}\right)\times48\times48\times3600\times3600$$

$$= \frac{1}{2}\times\left(\frac{1}{3600}\right)g\times48\times48\times3600\times3600$$

$= 40642000$ m
$= 40642$ km

Let us test whether this distance predicted by the law of gravitation is correct. Let us calculate the distance through which the moon falls in two days by making a scale drawing of the orbit of the moon Figure 8 7 shows the circular orbit of the moon. The scale used is 50,000 km = 1 cm The orbit of the moon which is a circle of radius 384400 km is shown by a circle of radius 7.7 cm In 27 days the moon covers an angle of 360°. In 2 days, therefore, it will traverse through an angle of 26.6 degrees The point P, therefore, represents the position of the moon after 2 days. The distance that the moon falls is, therefore, represented by the length AC which, in the drawing, is 8 mm Multiplying by the scale factor 50,000, we get the actual distance through which the moon falls in two days equal to 40,000 km. This answer is very close to the value predicted from the law of gravitation



Scale 1cm = 50,000 km

Fig.8.7 *Scale drawing of the motion of the moon in its orbit*

It was Newton who first calculated this result to test his law of gravitation. This calculated distance agreed beautifully with the observed orbit of the moon. Then Newton knew that the law of gravitation which he had proposed must be right.

We can perform the same calculation for the planets which orbit round the sun. It is the gravitational attraction of the sun that keeps the planets in their orbits, just as the moon goes round the earth due to the attraction of the earth (see Figure 8 8).

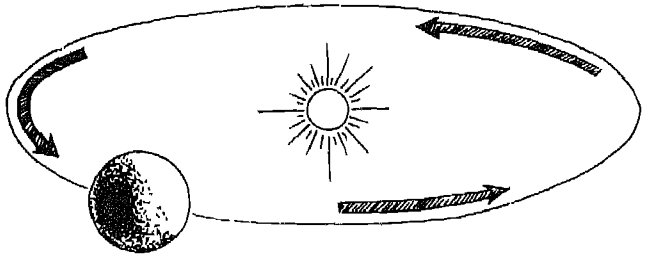


Fig 8.8 *Earth in its orbit around the sun*

IN THE LANGUAGE OF MATHEMATICS

If we denote

mass = m

gravitation constant = G

force = f

distance = r

acceleration due to gravity = g

radius of earth = R_e

mass of earth = M_e

$$F = G\frac{m_1 m_2}{R^2} \qquad F = mg$$

$$g = G\frac{m_e}{R_e^2}$$

QUESTIONS

Choose the right answers in the following

1 The force of gravitation between two bodies does not depend on
   (a) their separation.
   (b) the product of their masses.
   (c) the sum of their masses.
   (d) the gravitation constant.
2 Newton's law of gravitation
   (a) can be verified in the laboratory
   (b) cannot be verified but is true.
   (c) is valid only on earth
   (d) is valid only in the solar system
3 If a planet existed whose mass was twice that of the earth and whose radius 3 times greater, a 10 kg mass on its surface would weigh

(a) 2 2 newton
(b) 4 4 newton
(c) 6 7 newton
(d) 13 3 newton

4 When a space ship is at a distance equal to two earth's radii from the centre of the earth, its gravitational acceleration is
(a) 19.6 m/s^2.
(b) 9.8 m/s^2
(c) 4.9 m/s^2
(d) 2.45 m/s^2

5 If a planet existed whose mass and radius were both half those of the earth, the acceleration due to gravity at its surface would be
(a) 19 6 m/s^2
(b) 9 8 m/s^2
(c) 4 9 m/s^2
(d) 2 45 m/s^2

6 The acceleration due to gravity
(a) has the same value everywhere in space.
(b) has the same value everywhere on the earth
(c) varies with the latitude on the earth
(d) is greater on the moon due to its smaller diameter

7 The weight of an object
(a) is the gravity of the matter it contains.
(b) refers to its inertia
(c) is the same as its mass but expressed in different units.
(d) is the force with which it is attracted to the earth

8. A stone is dropped from a cliff Its speed after it has fallen 100 m is
(a) 9 8 m/s
(b) 44 2 m/s.
(c) 19 6 m/s
(d) 98 m/s.

9 A ball is thrown up and attains a maximum height of 100 m Its initial speed was
(a) 9 8 m/s
(b) 44.2 m/s
(c) 19.6 m/s
(d) 98 m/s

10. A stone dropped from the roof of a building takes 4 s to reach the ground The height of the building is
(a) 19 6 m.
(b) 39 2 m
(c) 156 8 m
(d) 78 4 m

11 When an object is thrown up, the force of gravity
(a) is opposite to the direction of motion
(b) is in the same direction as the direction of motion.

(c) decreases as it rises up

(d) increases as it rises up

12. In vacuum all freely falling objects

(a) have the same speed

(b) have the same velocity

(c) have the same acceleration

(d) have the same force

13. What is the mass of an object whose weight is 49 newton?

14. How much would a 70 kg man weigh on the moon? What would be his mass on the earth and on the moon?

15. The earth's gravitational force causes an acceleration of 5 m/s^2 in a 1 kg mass somewhere in space. How much will the acceleration of a 3 kg mass be at the same place?

16. A stone is dropped from the edge of the roof.

(a) how long does it take to fall 4.9 m?

(b) how fast does it move at the end of that fall?

(c) how fast does it move at the end of 7.9 metres?

(d) what is its acceleration after 1 s and after 2 s?

17. A stone drops from the edge of the roof. It passes a window 2 metre high in 0.1 second. How far is the roof above the top of the window?

18. A boy on a cliff 49 m high drops a stone. One second later he throws a second stone after the first. They both hit the ground at the same time. With what speed did he throw the second stone?

19. If you weigh 60 kg on earth, how far must you go from the centre of the earth so that you weigh 30 kg?

CHAPTER 9

SIMPLE PENDULUM AND RESTORING FORCE

IN CHAPTER 6 we studied the motion of a body moving with constant speed in a straight line. We learnt to find the distance travelled by such a body in any given time. We then observed that bodies rarely move at the same speed. They change their speed or direction of motion due to the forces acting on them. This led us to study the motion of accelerated bodies. To begin with we studied the motion of objects moving with uniform acceleration. Let us now study a type of motion which repeats itself, that is—periodic motion.

Activity 1

Take a small stone or a pebble and tie it to the end of a string. Suspend the string as shown in Figure 9.1 so that the pebble is free to swing. Now raise the stone slightly to one side keeping the string taut and release the stone. What motion does the stone perform?

The string with a mass at the end which is free to swing is called pendulum. Notice that the stone swings to and fro. It rises to extreme positions on both sides and reverses its motion. In other words, it oscillates. If you watch long enough you can observe that these oscillations gradually die down and finally stop.

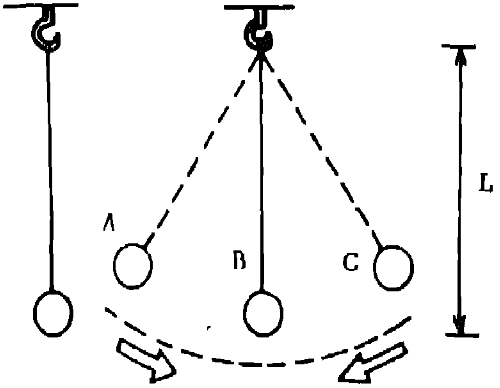


Fig 9.1 *A simple pendulum*

The length of the string from the point of suspension to the mass (in this case the stone) is called the length of the pendulum and we shall denote it by L. The point B is called the mean position of the pendulum.

The motion of the mass from its extreme position A to C and back to A is called an oscillation. You may find that the time taken for one oscillation is rather short and, therefore, difficult to measure accurately.

To find the time taken for one oscillation, we measure the time taken for a large number, say 20 oscillations. This time divided by 20 will give us the time taken for one oscillation.

Activity 2

Instead of a stone tie different objects like a small eraser, a bigger pebble or a small weight with a hook and fill in the following table Take care to check that the length of the pendulum is kept the same in each case.

Objects at the end of the string	*Time taken for 10 oscillations*	*Time taken for 1 oscillation*
Small eraser	?	?
Pebble	?	?
Small weight with a hook	?	?

Does the time taken for 1 oscillation change when the object tied at the end of the string B is changed? From the readings you have taken, do you think the time for one oscillation depends on the mass of the body tied to the string?

The time taken to complete 1 oscillation, that is the time taken to travel from one extreme position to the other and back is called the *periodic time* of the simple pendulum. It is sometimes also called its *period*, and is denoted by T.

Let us see if the period (T) of the pendulum depends on the length of pendulum.

Activity 3

Use different lengths L with the same stone and measure the period in each case.

Fill in the following table for different lengths of string.

What is the relation between L and T? Let us plot a graph of the length of the pendulum L and its corresponding period T, in the above activity.

We will get a graph which looks like Figure 9.2 a.

Length in cm L	*Time taken for 20 Oscillations*	*Time taken for 1 Oscillation* (period)
10	?	?
20	?	?
40	?	?
60	?	?
80	?	?
100	?	?

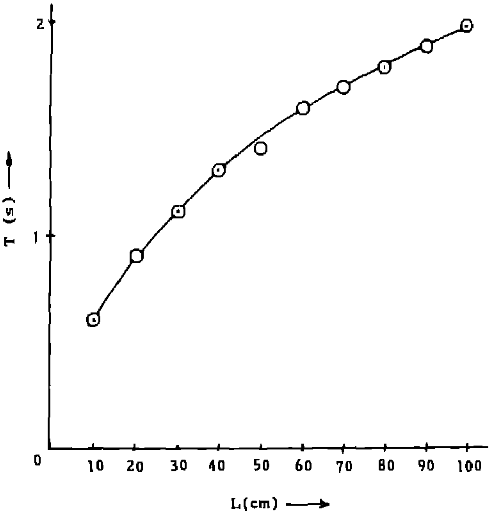


Fig 9.2a *Graph between time period and length of a pendulum*

What can you conclude from the graph? Have you seen a graph like this before? Try turning the graph paper around so that the graph looks like Figure 9 2b

This reminds us of the parabola which we studied at the end of Chapter 7 In such a graph the length L and period T are related by

$$L = \text{constant} \times T^2$$

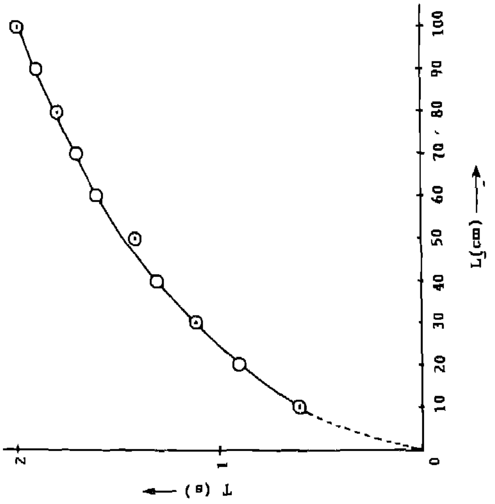


Fig 9.2b *Graph between L and T resembles a parabola*

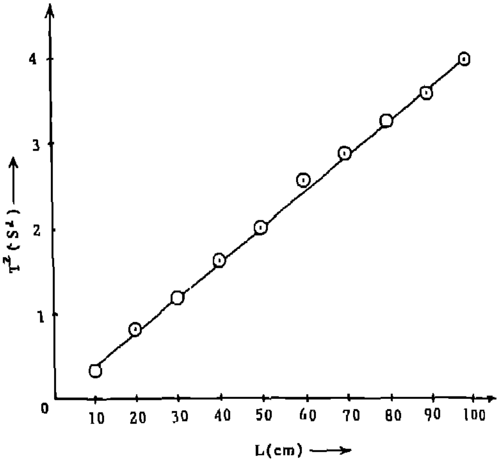


Fig 9 3 *Graph between L and T^2*

or $$\frac{L}{T^2} = \text{constant}$$

What would a graph of L against T^2 look like? We have seen a relationship of this sort before When an object moves with uniform speed the relationship between the distance travelled and the time taken is exactly like the one above, that is

$$\frac{\text{distance}}{\text{time}} = \text{constant speed}$$

Remember, the distance-time graph for such an object was a straight line So let us plot a graph of L on the X-axis and T^2 on the Y-axis

The straight line which is obtained confirms our guess that L and T are related by

$$L = \text{constant} \times T^2$$

We now have to evaluate the constants We could find the ratio from the observations that we have noted

If you have performed this experiment carefully you should get the following value for the constant

$$\text{constant} = 0.248$$

What are the units of this constant? If you go back to the relationship you can easily see that the constant has the same dimension as acceleration. Therefore

$$\text{constant} = 0.248 \quad \text{m/s}^2$$

In fact, when you learn more about the pendulum you will find that the constant is just the acceleration due to gravity divided by $4\pi^2$

$$\text{constant} = \frac{g}{4\pi^2}$$

The period of the pendulum T is, therefore, related to the length L by the relation

$$T = 2\pi\sqrt{\frac{L}{g}}$$

From this relation can you now find the length of the pendulum whose period is 1 second?

You will notice that the oscillations of the pendulum become smaller and smaller and then finally stop This slowing down is mainly due to the frictional forces exerted by air and the friction at the support If we put the pendulum in an evacuated tube and, therefore, eliminate air friction, the pendulum will continue to oscillate for a longer time.

If however, we immerse the pendulum in a jar containing a liquid, the oscillating pendulum would quickly come to rest In fact, the time in which it comes to rest tells us the extent of friction exerted by the liquid. This method is sometimes used to find the frictional forces exerted by the liquid

Forces acting on the weight of the pendulum

Observe the oscillation of the pendulum (Figure 9.1) and answer the following questions

Does the speed of the stone or the bob increase or decrease as it goes from

(1) B to C? (2) C to B? (3) B to A?
(4) A to B?

Remember that a force acting in the direction opposite to that of motion decreases the speed The slowing down of a ball thrown up is an example of this On the other hand, when the force acts in the direction of motion, the speed of an object always increases A ball speeding up when released from a height is an example of this.

What is the direction of the force responsible for the speeding up or slowing down of the bob as it oscillates?

The unbalanced force acting on the pendulum depends on the position of the bob If the bob is to the right of point B (in Figure 9 1), the force acts to the left When the bob is to the left of point B the force acts to the right Hence the speed of the bob always increases when it moves towards the mean position (B) The speed decreases as it moves away from B.

Such forces which act towards the centre or the mean position are called restoring forces. Let us see some examples of restoring forces

Activity 4

Tie a mass at the end of a spring as in Figure 9 4a. Now pull the mass to one side and release it. What motion does the mass perform?

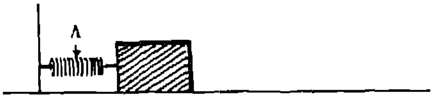


Fig. 9.4a

The force exerted by a stretched spring (Figure 9.4b) is an example of a restoring force A spring stretched by a small amount always tends to return to its normal length. If compressed it expands and if stretched it contracts once the force is withdrawn. The force on the mass tied at the end of such a spring is, therefore, always directed towards the point A as shown in Figure 9 4b.

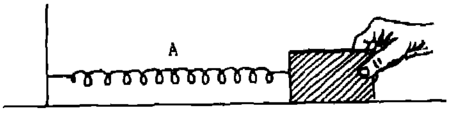


Fig. 9.4b

If there were no frictional forces the oscillations caused by restoring forces would continue forever However, as we saw earlier, a pendulum ultimately comes to a stop due to friction You may be familiar with the swing in a park which quickly stops if some force is not applied. Sometimes this slowing down is desirable In a spring balance, for example if the mass, did not come to rest quickly, we would hardly be able to read its weight

WHY DOES THE PENDULUM OSCILLATE?

Let us try to understand the origin .of the restoring force What would happen if the string of the pendulum was cut, when the bob is at its central position? Obviously, the mass at the end of the string would fall to the earth This, we have seen, is due to the gravitational attraction of the earth The string, therefore, holds the bob at a height by balancing the attraction of the earth. Thus there are two forces acting on the pendulum One is the gravitational attraction of the earth which pulls the bob towards the earth The second is the force exerted by the string along its length which prevents the bob from falling to the earth. This is shown in Figure 9 5a

When the bob is in the central position A (the mean position B in Figure 9 1) these two forces are balanced. As we saw such balanced forces produce no acceleration. If the bob were at rest at point A it would continue to remain at rest there

However, when the bob is at an extreme position, the string can no longer compensate and balance the pull of the earth. The bob, therefore, falls, but is kept at a fixed distance from the support by the string The trajectory of the bob is, therefore, an arc of a circle, as shown in Figure 9.5b.

When the bob falls and returns to the central position the pull of the earth

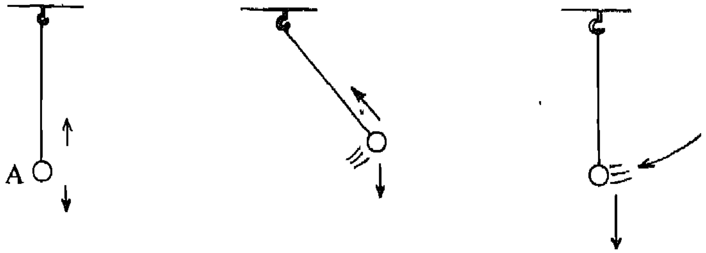


Fig. 9.5 a, b, c *Three positions of the bob of an oscillating pendulum*

is again balanced by the string That is, the total force on the bob is now zero But unlike before, the bob is not at rest It has a certain velocity In the absence of any force at the central position the bob continues ahead with the same velocity and crosses over to the other side (Figure 9 5c).

Once it crosses the mean position the string cannot balance the pull of the earth Its speed,therefore,decreases, until at the other extreme position, its speed is zero. It now begins its fall back to the earth exactly as it fell before Each time it arrives at the central position, it crosses over to the other side due to its inertia and the oscillations continue It is the combination of the two forces the pull of the string and the pull of the earth that give rise to the restoring force directed towards the point mean position

IN THE LANGUAGE OF MATHEMATICS

If we denote
period of a pendulum = T
length of a pendulum = L
acceleration due to gravity = g

$$L/T^2 = \text{constant}$$
$$L/T^2 = g/4\pi^2$$
$$T = 2\pi\sqrt{L/g}$$

QUESTIONS

Choose the right answers in the following

1 The period of the pendulum depends on its
   (a) mass,
   (b) length
   (c) amplitude
   (d) energy
2 The period of a pendulum whose length is 1 m is
   (a) about 2 seconds
   (b) about 1 second
   (c) about 9 8 seconds
   (d) about 4 9 seconds

3. If the length of the pendulum is doubled, the period of the pendulum
    (a) is halved
    (b) is doubled
    (c) become four times
    (d) become one-fourth
4. What is the period of a pendulum of length 9.8 metres?
5. Give some examples of restoring force
6. When is the speed of the bob of an oscillating pendulum maximum?

CHAPTER 10

WAVES

INTRODUCTION

In earlier chapters we studied the different types of motion an object can perform, such as motion with uniform velocity and accelerated motion. We then learnt to relate the acceleration of body to the force applied. We also derived the distance travelled by such a body in a given period of time. We next studied the motion of a body acted upon by a restoring force. We saw how the motion of such a body repeats itself after a fixed interval of time called its 'period'. In this chapter we shall study the motion of a collection of bodies—Wave Motion.

Activity 1

Let us make a small set-up. Take a metre rule and suspend seven heavy bobs as shown in the figure below (Figure 10.1).

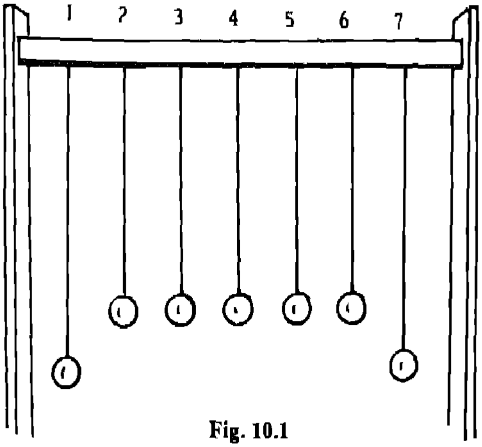


Fig. 10.1

Notice that the bobs 2, 3, 4, 5, 6 are at a fixed distance from one another and bobs 1 and 7 are at slightly longer distances. Then length of the strings holding bobs 1 and 7 are slightly longer than the length of the strings holding bobs 2, 3, 4,5 and 6. Now pass a string perpendicular to the 7 strings tying firm knots wherever this string meets each of the 7 strings so that you have an arrangement as shown in Figure 10.2.

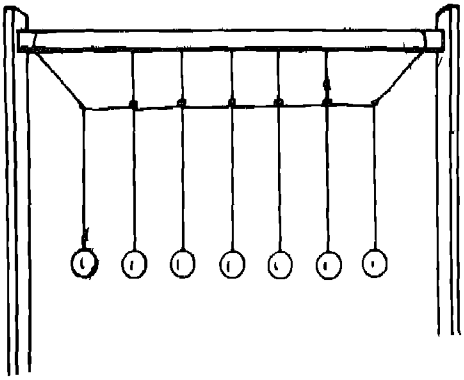


Fig. 10.2

See that the bobs are at the same height from the ground and at equal distances from one another Now lift one of the bobs (number 1) at the extreme left. Give it a slight push so that it starts oscillating in the plane of the strings. Take care that the bobs do not collide as they oscillate. You will notice that after some time the second bob starts oscillat-

ing, then the third, the fourth and so on until the last bob starts oscillating.

Remember you had only disturbed the first bob from its equilibrium position. Yet this disturbance 'travelled' along until the last bob felt this disturbance and started oscillating too. The oscillations of the first bob were able to cause oscillations in a bob far away from it without actually touching it

Such disturbances which travel are called *waves.* Sound is precisely this sort of motion When you speak you disturb air molecules close to your mouth. These in turn disturb the ones nearby This disturbance 'travels', oscillating the air molecules along its path until those molecules which are close to the listener's ear start oscillating too. The act of hearing then is nothing but decoding these oscillations. These oscillations vibrate the eardrum in the listener's ear which then sends the message to the brain through nerve connections.

In most waves there is always some mass that oscillates for a long time after it is disturbed In our setup, it was the bobs that oscillated In sound, it is the molecules of air that oscillate. We call these masses the medium of propagation

10.1 Pulses

With some waves the medium oscillates for a long time after it is disturbed. Like the set of seven bobs that continues to oscillate for a long time if left to itself. With some waves the medium oscillates for a short while and then returns to its original equilibrium Such waves of short duration are called ***pulses.*** Let us study an example of a wave of short duration or a pulse

Activity 2.

Take a slinky toy and fix it at one end in a hook (Figure 10.3). Hold the other end and give it a jerk. You will need some practice before you can jerk the slinky properly to create a pulse.

Before you jerk it, make sure that the slinky is parallel to the ground

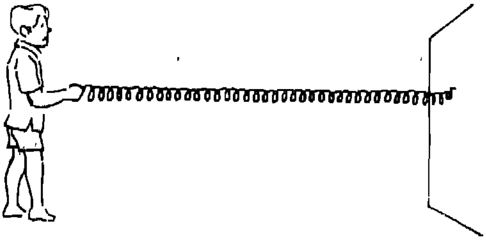


Fig. 10.3

As soon as you jerk it the shape of the slinky should be as shown in Figure 10.4.

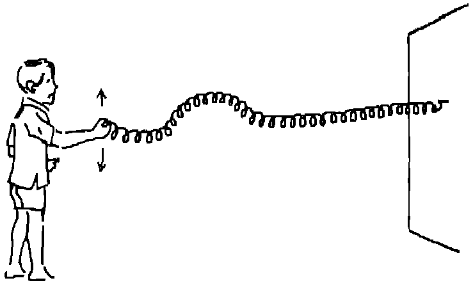


Fig. 10.4 *A pulse moving through a slinky*

The small hump travels and at successive instants looks as shown in Figures 10.5 and 10.6.

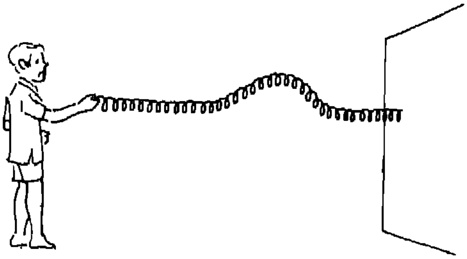


Fig. 10.5

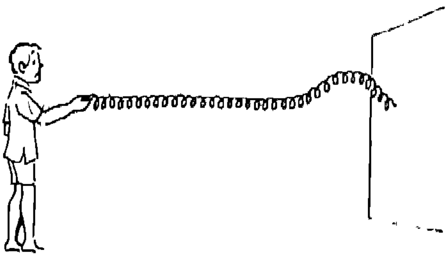


Fig 10.6

Notice how the slinky itself does not move, as a whole Only the individual parts of the slinky move in such a way that the hump moves to the right as a whole.

Energy travels from one part of the slinky to its adjoining part and so on disturbing the different parts of the slinky. Transfer of energy occurs

Let us study some more examples of such transfer of energy. If you drop a stone in a still pond, ripples will spread from the point where the stone touches the water. These ripples can make a nearby leaf on the surface of the pond bob up and down, but do not take the leaf away from where it was That is, the ripples move across the pond while the leaf oscillates on the surface. This is very much like the pulse on the rope. The individual points on the rope move up or down whereas the hump moves to the left or right In fact, by moving one end of a long rope up and down rapidly, you can create ripples on the rope too.

You can also see this transfer of energy in an arrangement of playing cards Arrange a pack of playing cards as shown in Figure 10.7. Now give the last card a slight push. You will see this disturbance propagating across the arrangement toppling the cards in succession until the last card is toppled.

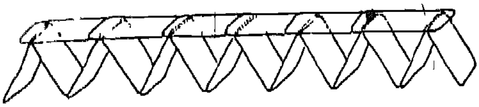


Fig. 10.7

10.2 Longitudinal and Transverse Waves

Let us go back to our set-up of the seven bobs and see what other disturbances are possible. We have already seen one such wave In the wave that we saw earlier, the bobs oscillated in the plane perpendicular to the plane in which the strings hang (Figure 10.8a).

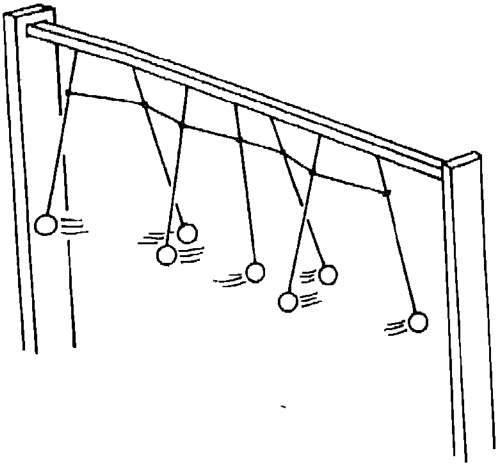


Fig. 10.8 a *A set-up to demonstrate a transverse wave*

Let us start with all the bobs at rest Let us now create a wave by tapping the first bob, so that it oscillates in the plane of the strings itself (see Figure 10.8b). You will have to be careful and disturb it only slightly so that the bobs do not collide with each other In this case also, the other bobs will pick up the motion of the first bob and oscillate in the same plane.

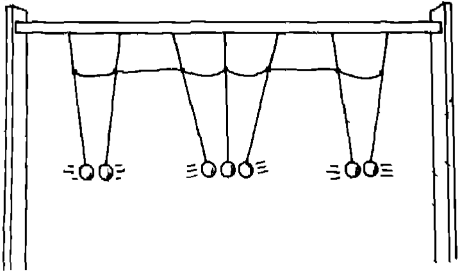


Fig. 10.8b *A set-up to demonstrate a longitudinal wave*

What is the direction in which the disturbance travels? What is the direction in which the bob oscillates?In the earlier case the bobs osciliated in the direction perpendicular to that in which the disturbance travelled In the latter case the direction in which the bobs oscillate and the direction in which the disturbance propagated are the same

We call the first type of wave a *transverse wave*. In a transverse wave, the particles of the medium oscillate in a direction perpendicular to the direction of propagation

The second type of wave is called the *longitudinal wave* In a longitudinal wave the direction in which the particles of the medium oscillate and the direction in which the wave propagates is the same.

Let us classify some of the waves we have seen. We had noted earlier that sound is an oscillation of air molecules about their equilibrium position These oscillations are exactly like the oscillation that we set up in the bobs in the second case. That is, the air molecules oscillate in the same direction in which the sound propagates. Sound is therefore an example of a *longitudinal wave*. On the other hand, let us look at the ripples on the surface of a pond. Here the direction of oscillation of the water is perpendicular to the direction of propagation of the ripple That is why the leaf moves up and down in the same place but the waves move across the surface Therefore the ***ripples on the water surface are transverse waves.***

The pulse on the slinky that we saw earlier (in Figure 10.4 through 10.6) was a transverse pulse. We can also make a longitudinal pulse on your slinky by compressing a small portion of your slinky and releasing it (Figure 10 9) You can see the compression travelling across the slinky, Can you create a longitudinal pulse in a rope?

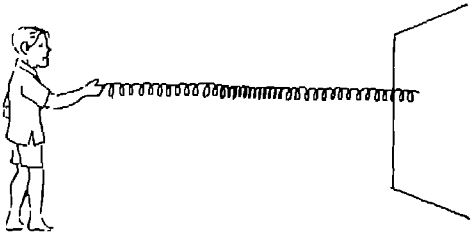


Fig. 10.9

10 3 Describing Waves in the Language of Mathematics

We have now seen different examples of wave motion. What distinguishes one wave from another? We have already seen the difference between transverse and longitudinal wave motion. To describe waves in a more precise way, we can use the language of mathematics. Let us first know how to do it for the simple longitudinal wave in the set-up of the seven bobs.

Figure 10.10 shows the oscillating

bobs at different times You will see that in some places the bobs are connected together. In some places there are no bobs at all. The table and the graph of the number of bobs in an interval and the distance of the interval are given below.

Interval	*Distance*	*No of bobs*
First	0	0
Second	1	2
Third	2	0
Fourth	3	3
Fifth	4	0
Sixth	5	2
Seventh	6	0

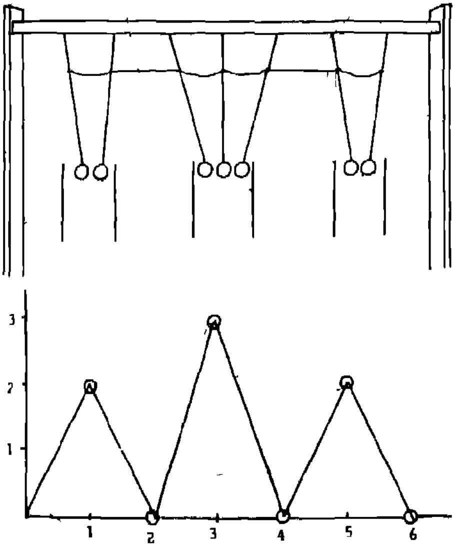


Fig. 10.10

For the second picture (Fig 10 11) the table and the graph would be:

Interval	*Distance*	*No of bobs*
First	0	1
Second	1	0
Third	2	2
Fourth	3	0
Fifth	4	3
Sixth	5	0
Seventh	6	1

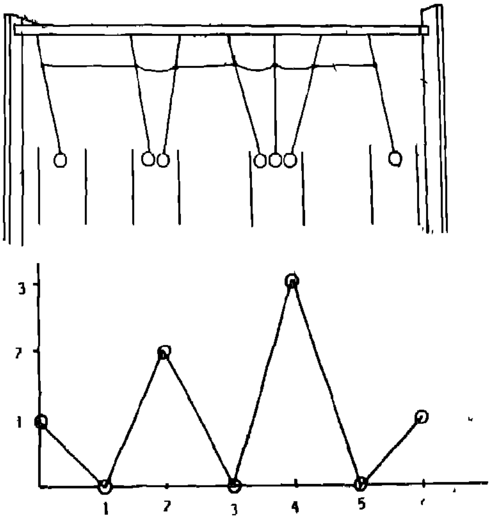


Fig 10.11

See how the graph of the number and distance at one time is different from the graph at a later time We can apply this idea to sound We saw earlier that sound is a longitudinal wave. The air molecules oscillate very much like the bobs of our apparatus In some places the air molecules like the bobs, are bunched together This is called *compression*. At other places there are very few air molecules This is called *rarefaction* Just as we plotted the number of bobs for interval versus the distance, we can plot the number of air molecules per unit interval, that is, the density versus distance for a sound wave. Of course, air molecules are much smaller than our bobs; and we have to choose very small intervals Shown in figure 10 12 a is a configuration of air molecules

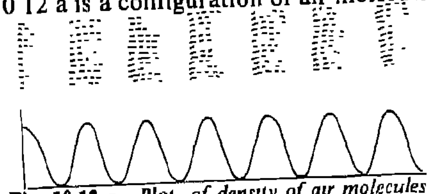


Fig 10.12 a *Plot of density of air molecules due to a sound wave*

for a sound wave. The graph of density versus distance is also plotted.

Due to the motion of the air molecules, the configuration will be different at a later time. Where there was a rarefaction, there may now be a compression and the graph will look different, as in Figure 10.12b

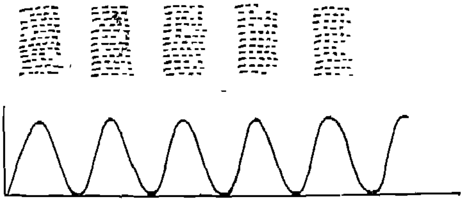


Fig. 10.12 b

We can plot such graphs for each of the waves that we have studied. For the ripple on a pond we could plot the height of the water surface or the distance from the centre. This graph at two different times will look as shown in Figure 10.13

Can you detect a change in the height at each point as time passes? Compare the heights of the water at a point at these two different times. Note how the disturbance occurs as distance increases.

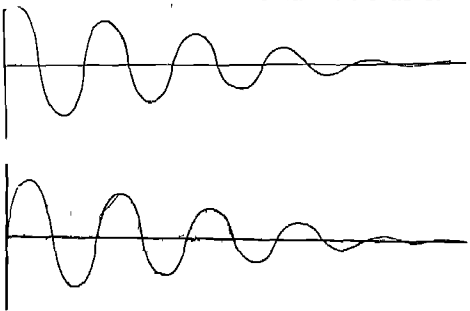


Fig. 10.13 *Displacement-time graph for a wave propagation*

We can plot such graphs for any wave motion. For example, the graph of the pulse on the rope is plotted in Figure 10.14 at two different times. Can you guess what is plotted on the Y-axis?

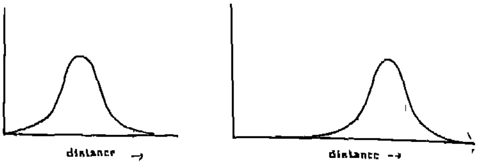


Fig 10.14 *Graph for motion of a pulse on a rope*

Can we also plot the pulse propagating through the playing cards? What will be on the X-axis and the Y-axis? Let us plot the height of the cards placed on top. Since the cards on the left have fallen down (Fig. 10.15) their heights will be low. The disturbance has not reached the cards on the extreme right and the height of the card here will be the maximum. In the middle, the cards are in process of falling. The graph of height versus distance will therefore look as in Figure 10.16a

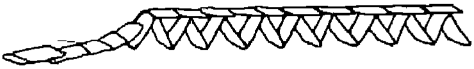


Fig. 10.15

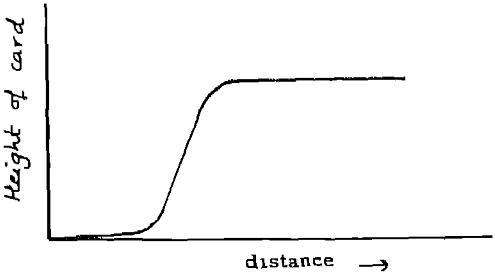


Fig 10.16a *Graph for height of cards versus distance*

As the disturbance travels it will topple some cards to the right and the graph at a later time will look as in Figure 10.16b.

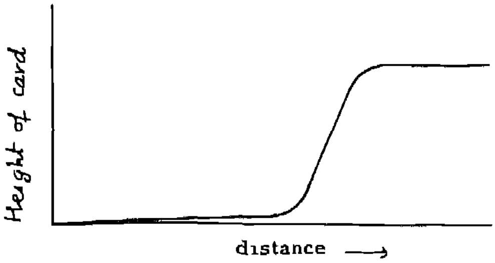


Fig. 10 16b

Can you see how the kink in the graph has shifted to the right?

10 4 Periodic Waves

Let us go back to our slinky and generate a series of pulses by jerking the end of the slinky up and down. If we plot the height of the slinky against the distance of such a wave at different times, we will get the graphs shown in Figures 10.17, 10 18, 10 19 and 10 20

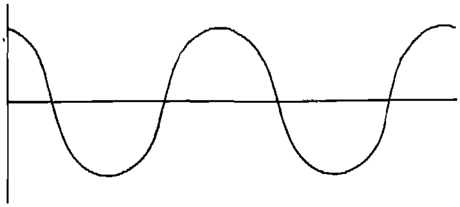


Fig.10.17

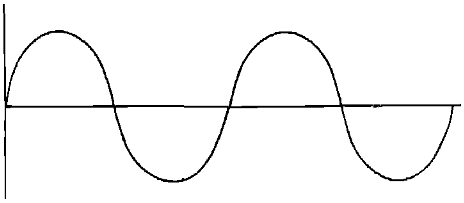


Fig-10 18

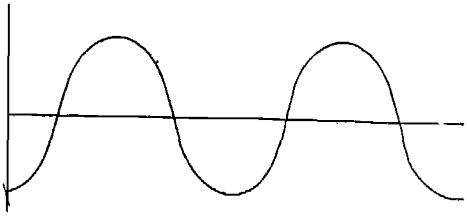


Fig.10.19

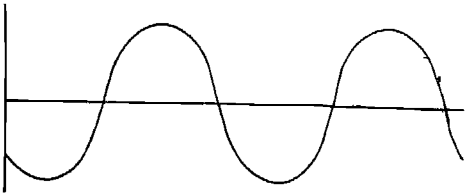


Fig 10.20

Notice how the individual points of the slinky shift up or down as time increases, and change the shape of the graph How is this graph different from the graph of a pulse? There are two differences. (1) Every point on the slinky is displaced, unlike a pulse where only a part of the slinky is displaced from its position That is, this wave stretches over the entire slinky (2) There is a basic pattern which repeats itself after a fixed distance

It is this repetition of the pattern that gives the wave its name—*periodic* The distance after which the pattern repeats itself is an important characteristic of the periodic wave It is called the *wavelength* of the wave The maximum displacement in the positive Y—direction is called a *crest* and the maximum displacement in the negative Y direction is called a *trough*, The distance between two consecutive crests or two consecutive troughs is also equal to the wavelength (Figures 10.21, 10 22). Notice how this pattern changes as time passes As time increases the crest and troughs marked by A, B, C, D move to the right.

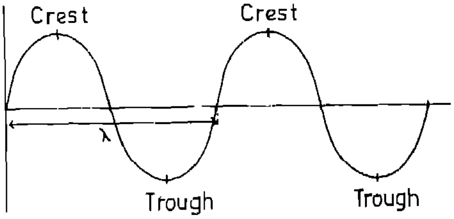


Fig. 10.21

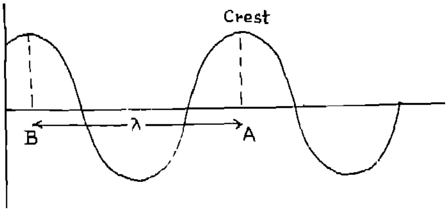


Fig 10.22

The time taken by the crest or a trough to move a distance equal to its wavelength is also a characteristic of the wave Let us denote this time by T. If the wavelength of the wave is denoted by λ (greek symbol called lambda), then the crest moves a distance of λ in time T The velocity of wave v is therefore given by

$$v = \frac{\lambda}{T}$$

The quantity $\frac{1}{T}$ is called the frequency and is denoted by the greek letter ν (pronounced "new") It has a special significance Let us calculate the number of crest passing a given point in one second.

Let us focus our attention on point A in Figure 10.22 which is a crest. As time passes this crest will move to the right. After how much time will the next crest arrive at point A?

Remember that the next crest has to travel a distance equal to the wavelength to arrive at A. The time a crest takes to travel a distance equal to the wavelength is T Therefore, we may say that the next crest will arrive T seconds later at A That is, one crest passes a given point every T second The number of crests passing a given point in 1 second is therefore

$$\frac{1}{T} = \nu$$

The frequency of a wave is therefore the number of crests that pass a given point in 1 second.In terms of the frequency, the equation connecting v and λ can be written as

$$v = \lambda \nu$$

This relation connects the wavelength and frequency of a wave with its velocity and holds for any periodic wave.

IN THE LANGUAGE OF MATHEMATICS

If we denote

time = t
fequency = ν
wavelength = λ
velocity = v

period of wave = T

$v = \lambda / T$
$\nu = \frac{1}{T}$
$v = \lambda \nu$

wave number = $\frac{1}{\lambda}$

QUESTIONS

Choose the right answers in the following

1 Sound waves are
   - (a) longitudinal.
   - (b) transverse.
   - (c) partly longitudinal, partly transverse.
   - (d) sometimes longitudinal sometimes transverse

2 Waves transfer 'X' from one place to another 'X' may be
   - (a) mass
   - (b) velocity.
   - (c) wavelength.
   - (d) energy.

3 A boat at anchor is rocked by waves whose crests are 100 m apart and whose velocity is 25 m/s. How often do the crests reach the boat?
   - (a) 2500 s.
   - (b) 75 s
   - (c) 4 s.
   - (d) 0.25 s.

4 Sound waves travel with a speed of about 330 m/s What is the wavelength of sound whose frequency is 550 hertz?

5 If the period of small ripples on water is 0.1 s and their wavelength is 5 cm, what is the speed of the waves?

6 The following graph shows the displacement versus distance of a pulse on a rope at two different times. Find the speed of the pulse

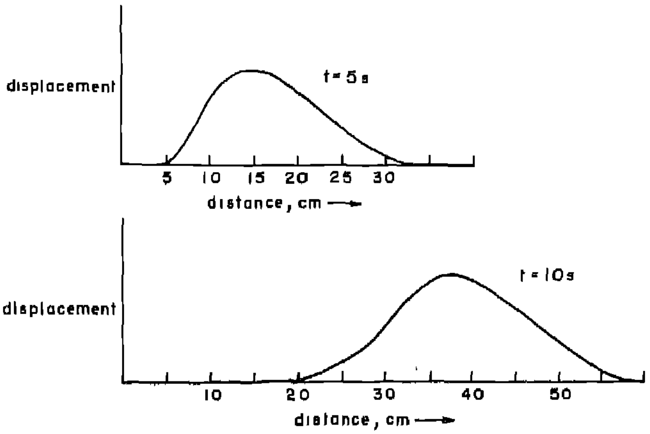


Fig.10.23

CHAPTER 11

WORK AND ENERGY

INTRODUCTION

WE HAVE learnt that work is done whenever the application of force produces a change The change may be of any sort—say a change in the position of an object The change may be in the velocity of an object or the change could be in the shape of an object, its chemical composition, its temperature or even its colour Every change involves work

The ability to do work, that is, to make changes is called energy. *If a body has the ability to do work, we say that the body has energy.*

11.1 **Different Kinds of Energy**

A moving object can do work For example, a moving marble can displace stationary marbles, that is, change their position. A speeding bullet can damage object placed in its path. Wind can be made to turn the blades of a windmill. This ability to do work based on motion is called *kinetic energy*

An object can also do work by virtue of its position or shape. For example, a stone raised to a height above the ground can do work when it falls A raised hammer when brought down on a nail can drive it into a wedge A compressed spring can do work as it expands The hands of a clock are in fact moved by such an expanding spring The energy possessed by objects because of their position or shape is called *potential energy.*

Can you say if the following objects have energy? If they do, identify whether the energy is kinetic, potential or a combination of the two.

1 A ceiling fan which has been switched off
2 A man climbing a hill
3. A flying bird
4. Water in the reservoir of a dam
5 A spring expanded beyond its normal shape
6. A rubber-band lying on a table
7 A stretched rubber-band lying on the ground

We saw earlier that an object can have both potential and kinetic energy. For example, a stationary stone on the top of a hill has only potential energy. But as it begins to roll downhill, it has both kinetic and potential energy. At the bottom of the hill it has only kinetic energy An aeroplane flying at a height has both potential and kinetic energy. The sum of the potential and kinetic energies of an object is called its *mechanical energy.*

We know that energy can neither be

created nor destroyed It can only be converted from one form to another or transferred from one object to another Whenever an object does work, it loses some energy When you lift a stone from the ground and raise it to a height you have done some amount of work. As a result of doing this work, you lose some energy. On the other hand, the stone which you raised gains in potential energy When we kick a ball we do work In doing this, we lose energy stored in our body and the ball gains in kinetic energy in the process This happens whenever work is done The object that does work loses energy and the object on which work is done gains energy In the examples we have seen so far, the energy we lose in doing work appears either as kinetic or potential energy in the object on which work is done The energy we lose in doing work may appear in other forms also. When we rub our palms vigorously against each other we do work The energy lost in doing this work appears in part as heat energy

DOES EVERY CHANGE INVOLVE WORK?

We have said earlier that any change involves work Sometimes the change may not be easily visible For example, do you think the boy in Figure 11 1 is doing work? You may be tempted to conclude that he is not. After all, nothing seems to be changing. The position of the boy remains the same, the position of the weight remains the same and no object in the picture is moving But if you were to hold the weight in your outstretched hand, standing in the same position, you would quickly feel tired, and lose energy.

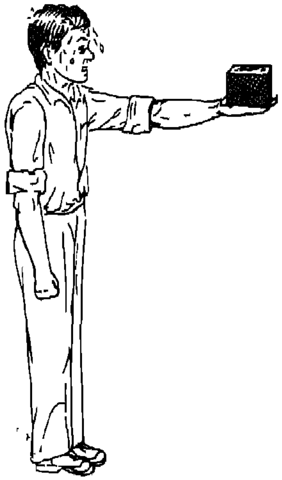


Fig. 11.1

Outwardly, nothing seems to be changing, yet there are indeed a lot of changes taking place. For example, the weight in your hand stretches your muscles, that is, changes their shape. The heart has to pump more blood to these muscles Complex chemical reactions take place and it is these changes that cost energy and make you tired. In fact if you wait long enough you may even see some outward changes. For example, you may see small drops of sweat. We, therefore, have to be very careful in observing changes to establish whether work is done or not.

We have said that energy is the ability to do work Can we measure the amount of work done in bringing about any change? Let us see what the quantities are on which the amount of work done depends. Let us try to move a block of wood on a flat table It is easy to guess that the amount of work done depends on the distance through which the block is moved For example, the quantity of fuel burnt up in a car depends on the distance travelled by the car It can also be checked that to travel twice a given distance at the same speed we need approximately twice the amount of fuel The amount of work done depends on the force that is applied to produce motion If we push harder we do more work Since the amount of work done depends on the force applied and the distance travelled, we can define work done as

Work done = force × distance

The units of measuring work done depend on the units of measuring force If force is measured in newton and distance in metres, the units of work are newton-metre The unit newton-metre is called a *joule* in honour of the British scientist James Joule This unit joule is same as the one used for heat.

Let us find the work done in a simple case (Figure 11 2) How much work is done in lifting a stone of mass m from the ground to a height of h metres above the ground? We have seen that earth attracts the stone with a force

$$F = \frac{GM_e\, m}{R_e^2}$$

$$= mg, \text{ where } g = \frac{GM_e}{R_e^2}$$

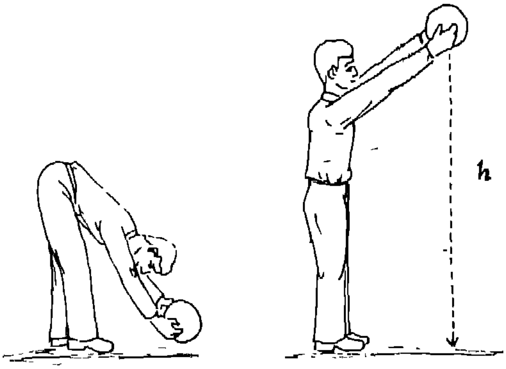


Fig. 11.2

M_e is the mass of the earth, R_e its radius and g is the acceleration due to gravity. To lift the stone to a height h, we have to apply an equal force mg in the opposite direction to overcome this gravitational attraction. The distance that the stone is moved through is h The work done is, therefore,

$$\text{Work} = \text{force} \times \text{distance}$$
$$= mg\,h$$

Since work is done on the stone, the potential energy of the stone has increased Due to this increase in energy the stone now has the ability to do work In fact the stone has the ability to return to us exactly mgh joule of work which was done on it We, therefore, say that the energy of the stone is mgh joule

You will have observed that energy and work done are measured in the same units Energy is also measured in joule.

We often find that pushing against heavy immovable objects like a huge boulder or a full cupboard or the walls of your house tires us quickly and reduces our energy. However, we do not find any evidence of displacement and, therefore, the work done appears to be zero.

The work done by us on the object is indeed zero However, the work done on our own bodies is not zero. Our muscles are stretched, our blood is displaced to the straining muscles and it is in making these displacements that energy is lost. In fact even if we had not pushed a heavy object but just strained our muscles with equal effort, we would have been equally tired.

In the above example the object was displaced in the same direction as the direction of the applied force However, if the displacement is not in the same direction as the applied force, the work done is no longer given by the simple product "force × distance"

When the displacement is not in the same direction as the force, the work done is defined as

work done = force × distance moved in the direction of the force

In Figure 11 3, a block is pulled at an angle to the ground, shows its final position due to the pull

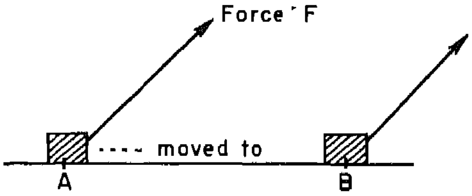


Fig 11 3a

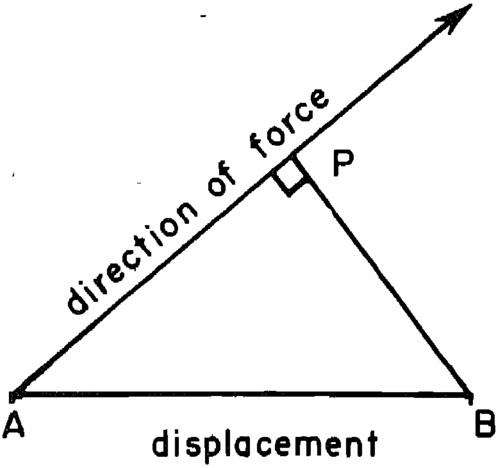


Fig 11.3b

To find the work done in this case we find the projection of the displacement in the direction of the force The projection AP is the distance moved in the direction of the force. The work done is, therefore,

work done = F × length of AP

What would happen if the displacement were in a direction perpendicular to the force In this case, the projection of the displacement along the direction of the force is zero The work done is, therefore, zero To find the work done, therefore, we must multiply the force by the distance moved in the direction of the force

We have found the potential energy of the stone raised to a height h Can we now find the kinetic energy of an object of mass m moving with velocity v . What would happen to the energy of the stone if it were released from the height h? As it falls, its potential energy would decrease and its kinetic energy would increase When it reaches the ground, its potential energy would be zero and all its energy would be kinetic energy Since the energy of the stone does not change, the potential energy of the stone at the height h should be equal to the kinetic energy at the ground If the stone were released with zero velocity, it would accelerate due to the attraction of the earth The magnitude of this acceleration would be

$$a = g$$

We can find the velocity of the stone when it reaches the surface of the earth by using the relation between distance and velocity for an accelerating object The relation is

$$v = \sqrt{2gh}$$

The energy of the stone at the ground, which is its kinetic energy, is therefore equal to

$$\begin{aligned} mgh &= mg\left(\frac{v^2}{2g}\right) \\ &= \frac{1}{2}mv^2 \end{aligned}$$

The kinetic energy of an object of mass m with a velocity v is given by $\frac{1}{2}mv^2$

ESCAPE VELOCITY

All slow-moving projectiles fall back to the earth because of its gravitational pull What should be the energy of the projectile so that it can overcome earth's gravity and escape into space? This is a question of importance in rocketry and space missions What should the velocity of a rocket be so that it can escape the earth's pull?

We saw in Chapter 8, Equation 8 1, that the force of gravity between the earth (mass M_e, radius R_e) and an object of mass m is given by $F = G\,\frac{M_e\,m}{R_e^2}$ where G is the gravitational constant The rocket has to have sufficient energy to do work against the earth's gravity The work to be done = F ×

R_e The kinetic energy of the rocket = ½m v^2 where v is its velocity. For the rocket to overcome the earth's pull,

$$\frac{1}{2} m v^2 > \frac{GM_e m}{R_e}$$

$$v^2 > \frac{2GM_e}{R_e}$$

$$v > \sqrt{\frac{2GM_e}{R_e}}$$

$$\text{or} \qquad v > \sqrt{2 R_e g}$$

Using the values given in Chapter 8, we arrive at

$$v = 11.16 \text{ km/s}$$

A rocket with velocity greater than 11.16 km/s will escape into space

Notice that this escape velocity from the earth is the same for any object no matter what its mass is It depends only on the mass and radius of the earth.

The escape velocity from the moon is five times smaller Can you calculate and verify this?

IN THE LANGUAGE OF MATHEMATICS

If we denote

mass = m
velocity = v
height = h
acceleration due to gravity = g
momentum = m
energy = E

$$f = m\,a$$

distance = s
force = f
acceleration = a
work = W
time = t

$$W = f\,s$$

kinetic energy $= \frac{1}{2} mv^2$
potential energy = mgh
power P = W/t

$$v_2^2 - v_1^2 = 2a\,s$$

For a freely falling body

$$v_2^2 - v_1^2 = 2g\,s$$

QUESTIONS

Choose the right answers in the following:

1. An object of mass 1 kg has a potential energy of 1 joule relative to the ground when it is at a height of
   (a) 0 102 m.
   (b) 1 m.
   (c) 9 8 m.
   (d) 32 m
2. A total of 4900 joule was expanded in lifting a 50 kg mass. The mass was raised to a height of
   (a) 10 m
   (b) 98 m.
   (c) 960 m
   (d) 245,000 m
3. When the speed of a moving object is doubled its
   (a) acceleration is doubled.
   (b) weight is doubled
   (c) kinetic energy is doubled.
   (d) kinetic energy increases 4 times.
4. A 1 kg mass has a kinetic energy of 1 joule when its speed is
   (a) 0 45 m/s.
   (b) 1 m/s.
   (c) 1 4 m/s.
   (d) 4.4 m/s.
5. An iron sphere of mass 30 kg has the same diameter as an aluminium sphere whose mass is 10.5 kg. The spheres are dropped simultaneously from a cliff When they are 10 m from the ground, they have the same
   (a) acceleration.
   (b) momentum
   (c) potential energy.
   (d) kinetic energy.
6. Which would have a greater effect on the kinetic energy of an object doubling the mass or doubling the velocity?
7. A man drops a 10 kg rock from the top of a 5 m ladder. What is its kinetic energy when it reaches the ground? What is its speed just before it hits the ground?

8 A car weighing 1000 kg and travelling at 30 m/s stops at a distance of 50 m decelerating uniformly What is the force exerted on it by the brakes? What is the work done by the brakes?

CHAPTER 12

HEAT

INTRODUCTION

HEAT IS a form of energy A body has higher energy when it is hot than when it is cold Its molecules absorb the heat and move about more vigorously at higher temperatures In a gas, the molecules have sufficient kinetic energy in them so that each molecule moves about freely What happens when we cool a gas below its condensation point? The kinetic energy of its molecules is reduced, while the attraction between molecules is increased As a result the gas condenses into a liquid What happens when we cool a liquid below its freezing point? The energy of its molecules is further reduced, compared to the intermolecular forces of attraction The liquid freezes into a solid. Thus, the energy of the molecules in a substance is low in the solid state, higher when it becomes a liquid and highest when it changes its state and becomes a gas. The attraction between the molecules holds the solid state together Heating a solid increases the energy of the molecules until at the melting point, the intermolecular forces are overcome to the extent that the solid liquifies and starts flowing Further heating imparts more energy to the molecules of the liquid until at the boiling point, the kinetic energy of the molecules takes over and allows them to move quite independent of each other In a gas, thus, the attractive forces between molecules is the least (see Fig 12 1)

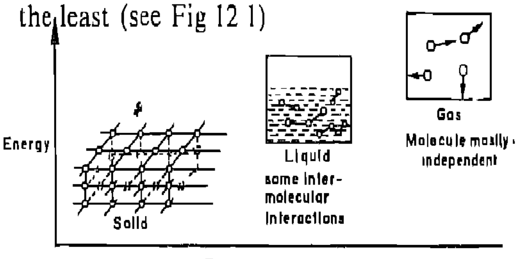

Energy
Solid
Liquid
some inter-molecular interactions
Gas
Molecule mostly independent
Temperature

Fig 12.1 *Intermolecular forces in the solid, liquid and gaseous phases*

The picture that we have presented is referred to as the kinetic molecular picture of heat It was proposed and refined by Maxwell, Joule, Planck, Debye, Einstein and many others In this picture, the molecules of a solid vibrate together about their mean positions as oarsmen in a boat do or as a spring does In a liquid, the molecules are somewhat freer to vibrate and to rotate. More importantly, molecules can move collectively from one place to another that is, flow with kinetic energy A gas offers its molecules independence so that they can freely move, independent of one another

12 1 Temperature

A quantitative measure of this energy of molecules is given by temperature Temperature thus expresses the degree of hotness (or coolness) of the substance. This is why the device that measures temperature is called a thermometer (*Thermo* refers in Latin to heat and *meter* to a measuring device) The earliest thermometer was developed by Galileo, who found that gases expand on heating. He used this property in an apparatus like the one shown in Figure 12 2.

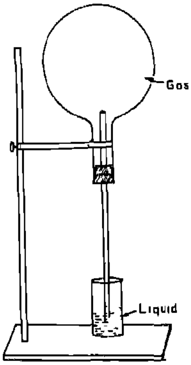


Fig. 12 2 *Galileo's gas thermometer As the temperature of the gas decreases, the liquid level will rise As it increases, the level will fall*

In order to express temperature quantitatively and in numbers, we need to have standards. We can then express temperatures relative to these fixed points. The temperature at which pure ice melts at normal atmospheric pressure is taken as such a standard or fixed point. The scientist called Fahrenheit (1686-1736) fixed this temperature as 32 degrees, and the temperature at which pure water boils at standard atmospheric pressure as 212 degrees. The slightly more convenient metric scale was suggested by Celsius (1701-1744) who fixed the two points at 0 and 100 degrees, respectively. While the Fahrenheit scale (°F) divides the two points in 180 degree intervals, the Celsius scale (°C) divides them into 100 degrees (hence the name centigrade). Thus 32°F = 0 °C and 212°F = 100°C Clearly, the Celsius scale is more convenient and is used in preference to the Fahrenheit scale. We shall use the Celsius scale in this book and not the Fahrenheit The latter is still used however, by doctors to measure the temperature of the human body. Figure 12 3 is what is called a nomogram that relates the two scales. The following equations tell us how to convert temperature from the Fahrenheit scale to the Celsius scale and *vice versa*

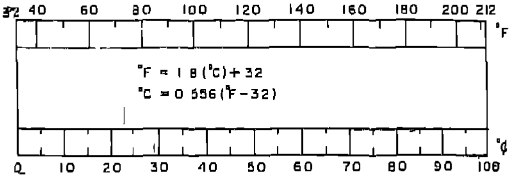


Fig 12 3 *The Fahrenheit and Celsius scales*

$°F = 1.8\,(°C) + 32$ (Equation 12 1)

$°C = 0\,556\,(°F - 32)$ (Equation 12.2)

The temperature of a healthy human body is 98.6°F What is it in °C? And when the temperature rises to 105°F due to high fever, it can be dangerous Doctors advise that the body be given "cold compresses" with towels dipped in ice-cold water. What is this high fever temperature in °C?

While we humans cannot tolerate the intense summer heat of 46°C, camels do so by raising their body temperatures to 42°C (see Chapter 15). What are these temperatures in the Fahrenheit scale? Let us use Equations 12 1 and 12 2

Temperature of the healthy body in °C $= 0.556\,(98\,6 - 32) = 37°C$

High fever in °C = 0 556 (105−32)
= 40.55°C

Intense summer temperature in °F
= 1 8 (46) +32 = 114.8°F

The camel's body temperature then
= 1.8 (42) + 32 = 107.6°F

Notice that while the camel has increased its body temperature this high, we humans still have a temperature differential of 9°C or 16 2°F. This makes us sweat a lot and lose water from the body.

Similarly, when the temperature outside is 0°C in the winters of the Himalayas, the temperature differential of 37°C (or 66 6°F) between us and the environment makes us suffer, and if we do not protect ourselves, our body can lose its heat and its temperature can drop to that of the environment Exposure to severe cold can even be fatal.

12.2 **Heat and Motion**

Here we note a general property of heat, that of flowing from a body at high temperature to one at lower temperature. How much of it flows and how fast? When does it stop? These are some interesting questions that we shall take up now In general, *heat energy flows from a hotter body to a colder one until the temperatures of the two become equal At this stage, the two are said to be in thermal equilibrium.* Also, notice from the above examples another important property of heat. *Heat always flows from a hotter body to a colder one* A cold body does not by itself (that is, spontaneously) become warmer This is a manifestation of the universal principle that all systems tend to be in the states of lowest possible energy.

What we have stated above is a very important natural law It says that it costs energy to heat a body above room temperature. We have to supply energy to the body from elsewhere. This is quite equivalent to the fact that we have to supply energy in order to lift a body (mass m) from the ground to any height 'h'. In this case, we are supplying it potential energy (mgh), where g is the acceleration due to gravity. In heating a body we supply its molecules kinetic energy ($1/2\ mv^2$) and they move with greater speed (v) at higher temperatures

Heat is also generated from the energy of motion Friction is a ready example of this Rubbing hands vigorously produces heat. Just think of all the steps involved when you light a matchstick to produce fire. Or think about why the rim of the wheel gets hot when you attempt to stop the moving wheel of a bicycle A meteorite, entering the earth's atmosphere, gets heated due to friction with the air and turns to vapour before it reaches the earth's surface In all these instances, the kinetic energy lost by an object due to friction appears in excessive form as heat or thermal energy

12 3 **Specific Heat**

A hotter body loses its energy to a colder one A cold body needs to be supplied with energy to become warmer On what factors does the amount of heat required to warm a substance depend? Let us conduct an experiment

Activity 1

(a) Take 500 ml of water in a vessel and measure its temperature (T_1). Now heat the water using a burner or stove for 2 minutes and measure the temperature rise (T_2) Note it down Remember — we shall use the Celsius scale .Hence you should use a centigrade thermometer and record in °C.

(b) Take a fresh lot of 500 ml of water at T_1. Using the same vessel and the same burner, heat this water for 4 minutes and now measure the temperature (T_3). You will find that (T_3 - T_1) is roughly twice the value (T_2 - T_1).

(c) Do the experiment again, this time taking 1 litre of water at T_1 and heat it using the same set-up, for 2 minutes and measure the temperature T_4. You will find that (T_4 - T_1) is about half the value of (T_2—T_1).

Part (b) of the activity shows the time-dependence of the heat intake and part (c) shows the dependence of the temperature rise in the amount of the material taken. Together we express these in terms of the *specific heat* of the material The specific heat denotes the amount of heat required to raise the temperature of 1 gram of a substance by 1°C

$Q = C.m.\Delta T$ (Equation 12 3)

where Q is the amount of heat supplied to m gram of a substance and ΔT is the rise in temperature. C is the specific heat and has the units of $\frac{Q}{m\Delta T}$. The units of heat are the calorie or the more modern and accepted joule (J) Mass is expressed in kg and ΔT in °C. Thus, the units of specific heat are J/kg/°C. Table 12.1 gives the C values of some common substances

TABLE 12 1

SPECIFIC HEATS OF SOME SUBSTANCES AROUND 20°C

Substance	*C, in J/kg/°C*
Water	$4\ 18 \times 10^3$
Marble	$0\ 90 \times 10^3$
Glass	$0\ 50 \times 10^3$
Iron	0.48×10^3
Copper	$0\ 39 \times 10^3$
Mercury	$0\ 03 \times 10^3$

Notice that water has the highest specific heat and mercury the lowest This has important consequences in heat absorption and flow through these materials as we will see shortly Note also that we have mentioned that these values of C are around 20°C. This means that the C value of a substance may change from one temperature to another This does happen in fact, and is because of the structure and organisation of the molecules in materials

Another quantity of importance is the *thermal capacity* also called the *heat content* This is simply the product mC where m is the mass and C the specific heat of a substance Thus the heat content or the thermal capacity is the amount of heat required to raise the temperature of an object by 1°C.

12.4 Some Calculations Using Specific Heat

Exercise We pour 2 litres of water at 80°C into a plastic bucket containing 10 litres of water at 20°C. What is the final temperature of the water?

In order to calculate this, we use the fact that heat flows from a hot body to a colder one, and that the final temperature reached is the equilibrium temperature. We also use the specific heat as a measure of the extent of flow. In this case, we will also assume two things (1) The density of water is 1kg/*l* so that 2 litres of water are taken as 2 kg and 10 litres as 10 kg This is because specific heat is expressed in kg and not in volume units, and (2) the heat exchange is only between the hot and the cold water. The plastic bucket is assumed to absorb very little or no heat Both these are reasonable assumptions, the density of water is very close to 1kg/*l* Also, we know that while plastic does absorb heat, it does so far less than copper or iron vessels

Let us call the final temperature of the water T_f What is the amount of heat lost by the 2 litres (or 2 kg) of water? Using Equation 12.3 we note that this would be

heat lost $= Q = C\ m\ \Delta T = C\ 2\ (80 - T_f)$

This heat lost is equal to the heat gained by the 10 litres of the cold water This heat gained is equal to

$$Q = C\ m\ \Delta T = C\ 10\ (T_f - 20)$$

heat lost = heat gained

$$C.2\,(80 - T_f) = C.10\,(T_f - 20)$$

$$160 + 200 = 10T_f + 2T_f$$

$$T_f = \frac{360}{12} = 30°C$$

The temperature of the water becomes 30°C

Exercise A brass rod of 0.2 kg mass at 100°C is dropped into 0.5 kg of water at 20°C The final temperature is 23°C What is the specific heat of brass?

Using Equation 12 3 first for brass

heat lost by brass $= C_b.\ m_b\ \Delta T_b$

$= C_b (0\ 2)(100 - 23)$

$= 15\ 4\ C_b$ J

Using the Equation now for water,

heat gained by the water

$= C_w\ m_w.\Delta T_w$

$= (4\ 18 \times 10^3)(0\ 5)(23 - 20)$

$= 6270$ J

heat lost = heat gained

$15\ 4\ C_b = 6270$

$\therefore C_b = 407 = 0.407 \times 10^3$ J/kg/°C

12 5 Thermal Expansion

Heating a substance increases the energy of its molecules. In a solid, the molecules or atoms are arranged in a regular lattice in three dimensions Heating leads in this case to an expansion of the lattice and the distance between the molecules increases This is reversible and cooling would return the lattice to its original arrangement In a liquid, heating would also lead to easier flow and "thinning down", or a decrease in the viscosity. In a gas, of course the increase in kinetic energy of the molecules upon heating is best seen The pressure of a gas inside a closed container increases upon heating This is seen dramatically when a soda bottle explodes in the summer heat This is why such soda or soft drink bottles are made of thick glass that can withstand the pressure.

Some common examples that illustrate the thermal expansion of solids are shown in Figures 12.4 and 12.5.

If the iron rails of the railway track in Figs.12 4a and b are not given the gap or

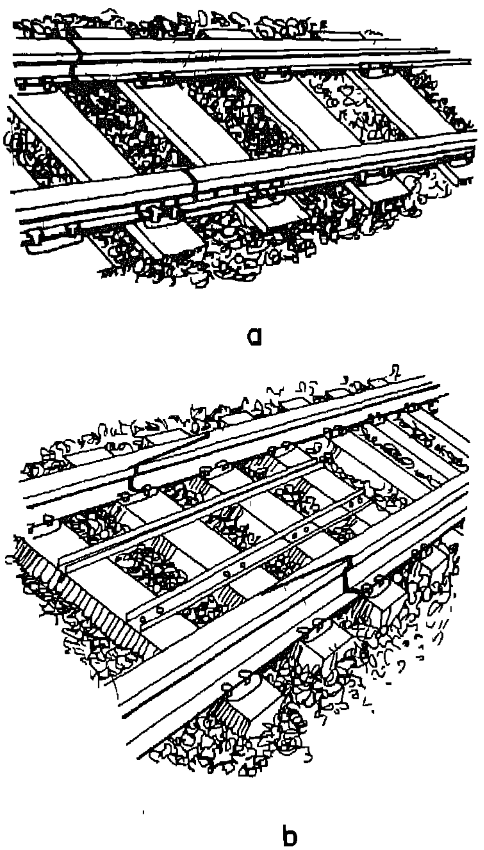


Fig. 12.4(*a*) *Gap* (**b**) *Wedge between two rails allowing for thermal expansion*

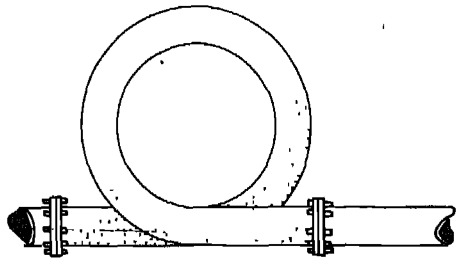


Fig. 12.5 a

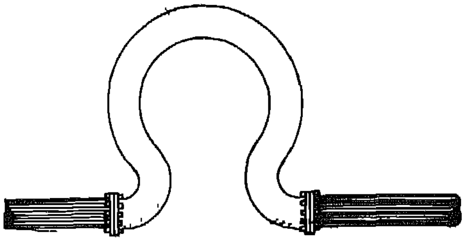


Fig 12.5 *Two designs of loops provided in long metal pipes used for carrying fluids*

the wedge in between, the track could get deformed when it expands upon getting heated in the summer Similarly, the loops in Fig. 12.5a and 12.5b are provided in order to avoid the strain that would develop in the pipes when the temperature changes

The extent to which a substance expands upon heating depends on the nature of the substance. It is quantitatively expressed in terms of the *coefficient of thermal expansion* normally symbolised by the Greek letter alpha, α.

If the length of a rod is l_1 at temperature T_1 and it becomes l_2 at a different temperature T_2, then the difference in the length $(l_2 - l_1)$ is proportional to the difference in the temperature $(T_2 - T_1)$

$$(l_2 - l_1) \propto (T_2 - T_1) \qquad \text{(Equation 12.4)}$$

or the *proportional* change in the length

$$\frac{l_2 - l_1}{l_1} \propto (T_2 - T_1) \qquad \text{(Equation 12 5)}$$

This is rewritten as

$$(l_2 - l_1) = \alpha \; l_1 (T_2 - T_1) \qquad \text{(Equation 12 6)}$$

or

$$l_2 = l_1 \left[1 + \alpha (T_2 - T_1)\right] \qquad \text{(Equation 12.7)}$$

α is the *coefficient of linear expansion* and is expressed as fractional change per °C We call this *linear* expansion since Equation 12 7 expresses the length or one dimension. When we heat a metal sheet instead of a metal rod, the sheet will expand in its length and breadth, each according to Equation 12.7. And when a metal block or brick is heated, its length, breadth and height will increase or its volume expand in the same fashion Table 12.2 gives the values of the coefficients of linear expansion of some solids

Table 12.2

VALUES OF α OF SOME SOLIDS

Pyrex glass	3×10^{-6} per °C
Soft glass	9×10^{-6} per °C
Steel	11×10^{-6} per °C
Iron	12×10^{-6} per °C
Gold	14×10^{-6} per °C
Copper	17×10^{-6} per °C

Note that copper expands almost six times as much as pyrex glass does. In general, metals have high values of α.

The expansion of metals with heat can be used to measure temperature It cannot be accurate, however, since α has a very low value. For example, what would be the change in length of a copper wire of length 10 metre when heated from 30°C to 60°C? Using Equation 12.8 and the value of α for copper, we see that

$$(l_2 - l_1) = 10 \times 30 \times (17 \times 10^{-6})$$
$$= 5.1 \text{ mm}$$

The expansion of the rod is very little, in fact far less than one per cent. The iron rails of the railway track have a smaller value of the expansion coefficient than copper and they also do not get heated to more than 45°C or 50°C in summer Their expansion is even smaller, and yet we have to make allowance for this when railway tracks are laid.

What about liquids? They expand to a greater extent than solids upon heating The expansion of a liquid is of course in its volume Therefore, we define a *coefficient of cubical expansion* rather than linear expansion here and denote it by the Greek letter γ (gamma), the corresponding equations are

$$(V_2 - V_1) \propto (T_1 - T_1) \qquad \text{(Equation 12.9)}$$

or

$$(V_2 - V_1) = \gamma \; V_1 \, (T_2 - T_1) \qquad \text{(Equation 12 9)}$$

or

$$V_2 = V_1 [\, 1 + \gamma \, (T_2 - T_1)] \qquad \text{(Equation 12.10)}$$

Table 12.3 gives the values of γ of some liquids around 20°C

Table 12.3

VALUES OF γ OF SOME
LIQUIDS AROUND 20°C

Mercury	18×10^{-5}	per °C
Water	21×10^{-5}	per °C
Benzene	122×10^{-5}	per °C

Notice that even the lowest value here, that of mercury, is ten-fold higher than the expansion coefficient of solids The γ value of benzene is six-fold higher than of mercury Benzene would thus be a more sensitive fluid in a thermometer than mercury, in order to measure very small temperature changes. Yet mercury is the preferred fluid and benzene is seldom used Can you think of the reasons why it is not used?

12.6 Change of State

Activity 2

Take about 200 g of crushed ice in a glass beaker of 500 ml volume or a similar vessel. Set up the apparatus as shown in Figure 12.6a. Use a centigrade thermometer, dip it in the ice and measure the temperature. It should be 0°C Using a burner or a spirit lamp start heating the ice on a constant and slow flame. Note the temperature every few minutes and make a plot of the temperature against time as shown in Figure 12 6b. You will notice that the temperature of the ice does not change, although it is being heated (You must continuously stir the ice-water mixture so that the temperature is uniform throughout) In fact, the temperature remains 0°C until all the ice has melted It then rises steadily as the water is heated up to 100°C when the water starts to boil At this point again, the temperature stays constant at 100°C until the water evaporates

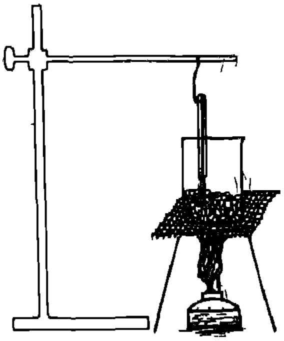


Fig 12.6 a *Set-up for heating ice and water*

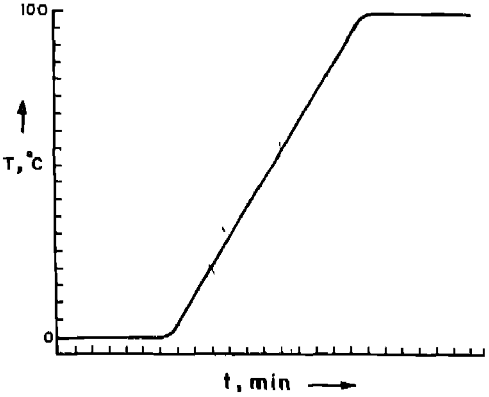


Fig. 12.6 b *Plotting the time-temperature graph*

Let us consider the results of the experiment that you performed and plotted as in Fig.12.6b. First, even though the ice was getting heated, the temperature did not rise beyoud 0°C. All the heat energy supplied to the ice during this time was used up in melting the ice and changing its state from solid to liquid We could not measure this heat using a thermometer; it was hidden or latent in the system. This heat is referred to as the *latent heat of melting*. It is defined as the quantity of heat required to completely change the state of 1kg of solid at its melting point, into the liquid state The latent heat of melting of ice is 335 J.

If this heat could not be measured by a thermometer, where did it go? It was utilised in increasing the energy of the water molecules in ice at 0°C, until they overcome the intermolecular forces holding them together in the solid lattice Once they overcome these to the extent that the solid melts and liquid forms, the temperature of the liquid water starts rising from 0°C. It steadily increases until again at 100°C, a change of state from the liquid to gas occurs. The temperature stays constant at 100°C during this process. *Latent heat of vaporisation* or *latent heat of boiling* is now provided at this point to produce steam from water. The latent heat of vaporisation is the heat required to completely vaporise 1kg of a liquid at its boiling point This has a value of 2260 J for water

Evaporation is the process of a liquid changing into its vapour even below its boiling point Evaporation of water from a cup or a pot occurs at room temperature, and is faster when the temperature is higher It is also faster when the liquid is kept or spread on a larger surface area The heat of evaporation is taken up by the liquid from the environment, and the environment cools down appropriately. Perspiration or sweating is a process that takes advantage of this point On a hot day, we perspire and the evaporation of the sweat water cools our skin Trees put out or acquire more leaves in summer Transpiration from the leaves or the evaporation of water helps them to keep cool.

There is always some amount of water vapour present in the air around us. This vapour comes from the evaporation of rivers, lakes and oceans and also from various life activities The amount of water vapour in air is referred to as humidity At any given temperature, the amount of water vapour that can be present in the air is fixed It cannot exceed a maximum humidity value, and if it does, it will condense and fall off from the air as water. For example, at 25°C the air cannot hold more than 23g of water vapour per cubic metre of air at normal pressure The value of this humidity increases at higher temperatures, since more evaporation occurs and also the pressure can increase At 40°C the absolute humidity value is 51g per cubic metre of air. Thus, when the air is cooled from 40°C to 25°C, it will "sweat out" its water content by about 28 g per cubic metre You can see this happen as the water condenses on the *outside* of a tumbler containing iced water

The amount of water vapour in air is usually lower than the absolute humidity or saturation value We refer to the amount in terms of *relative humidity* (RH) which is the percentage of the amount actually present to the absolute humidity value Thus, if air contains 25.5 g of water vapour at 40°C per cubic metre, the relative humidity is (25 5/51) × 100 or 50% High values of R.H. give us a sultry feeling and our clothes do not dry easily The R.H in coastal areas is higher than in the plains R H values of about 50% are considered comfortable at an outside temperature of about 22-25°C

IN THE LANGUAGE OF MATHEMATICS

If we denote

°C = temperature in the centigrade or the Celsius scale

$°F$ = temperature in the Fahrenheit scale
m = mass C = specific heat
l = length V = volume
α = coefficient of linear thermal expansion
γ = coefficient of cubical expansion
T = temperature Q = heat

$$°F = 1.8\,(°C) + 32$$
$$°C = 0.556\,(°F - 32)$$
$$Q = m\,C\,(T_2 - T_1) = m.C\,\Delta T$$
$$l_2 = l_1[1 + \alpha \Delta T]$$
$$V_2 = V_1[1 + \gamma\,\Delta T]$$

QUESTIONS

Choose the right answer

1. When an object is heated, the molecules that make up the object
   - (a) begin to move faster
   - (b) lose energy.
   - (c) become heavier.
   - (d) become lighter
2. Heat energy of an object is
   - (a) the average energy of the molecules of the object
   - (b) the total energy of the molecules of the object
   - (c) the average velocity of the molecules of the object.
   - (d) the average potential energy of the molecules of the object
3. The temperature of a body is an indicator of
   - (a) the total energy of the molecules of the object
   - (b) the average energy of the molecules of the object.
   - (c) the total velocity of the molecules of the object
   - (d) the average velocity of the molecules of the object.
4. A and B are two objects The temperature of A is greater than that of B. This means that
   - (a) the molecules of A are moving faster on the average than the molecules of B
   - (b) the total energy of A is greater than the total energy of the molecules of B
   - (c) the average potential energy of A is greater than the average potential energy of B.
   - (d) the heat content of A will always be greater than that of B

5. Two blocks of lead, one twice as heavy as the other, are both at 50°C. The ratio of the heat content of the heavier block to that of the lighter block is
   - (a) 0.5.
   - (b) 1.
   - (c) 2.
   - (d) 4.
6. The quantity of heat required to change the temperature of 1 kg of substance by 1°C is called its
   - (a) specific heat.
   - (b) the total energy.
   - (c) the latent heat
   - (d) heat of fusion
7. When a vapour condenses into a liquid
   - (a) it absorbs heat.
   - (b) it evolves heat
   - (c) its temperature rises
   - (d) its temperature drops
8. A 20 kg storage battery has an average specific heat of 0.2 kcal/kg °C. When fully charged the battery contains 2 kcal of energy. If the entire energy were used to raise the temperature, its temperature would increase, by
   - (a) 20°C
   - (b) 200°C.
   - (c) 0.5°C.
   - (d) 0.2°C.
9. If we take 15 g of water and add 60 calories of heat to it, what is the rise in its temperature?
10. How much heat must be added to raise the temperature of 100 g of water from 5°C to 95°C?
11. How much heat is required to raise the temperature of 150 g of iron from 20°C to 25°C?
12. How does the heat required to raise the temperature of water by a certain amount compare with the heat required to raise the same mass of iron by the same amount?

CHAPTER 13

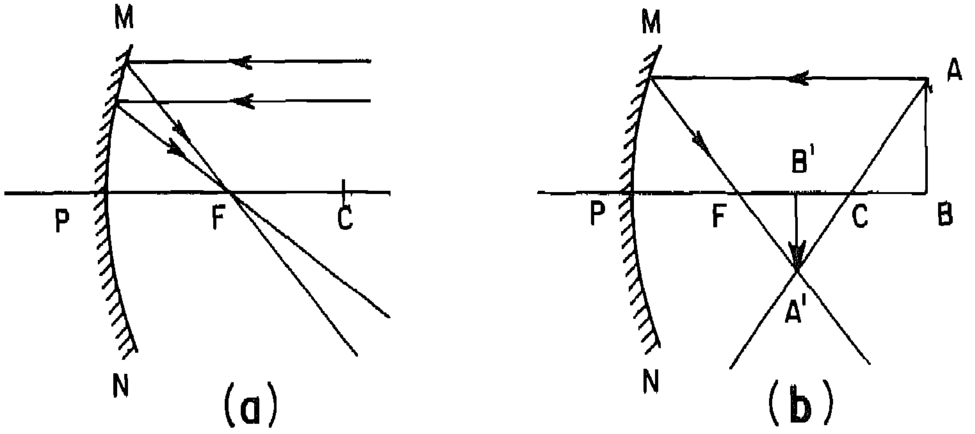
LIGHT

INTRODUCTION

LIGHT IS a form of energy We get light from various types of sources, both natural and man-made. We detect light through our eyes that are one of the most wonderful sense organs with which nature has endowed us Through these eyes we can explore the wonderful world of light and colour The eye is in fact an optical instrument, just as a camera and a telescope are. We shall be studying the structure and working of human eyes and some optical instruments in this chapter. The laws of reflection and refraction of light will be used for this study The ideas relating to the formation of an image by spherical mirrors and lenses will help us understand the working of these optical instruments

13.1 Reflection by Spherical Mirrors

You are already familiar with the laws of reflection and refraction You also know how to draw ray diagrams to obtain image formed by spherical mirrors for objects placed at different positions As a summary, Table 13 1 gives the position, size and nature of images formed by a concave mirror for different positions of the object. Figures 13 1 a-f illustrate the various situations.



(a) (b)

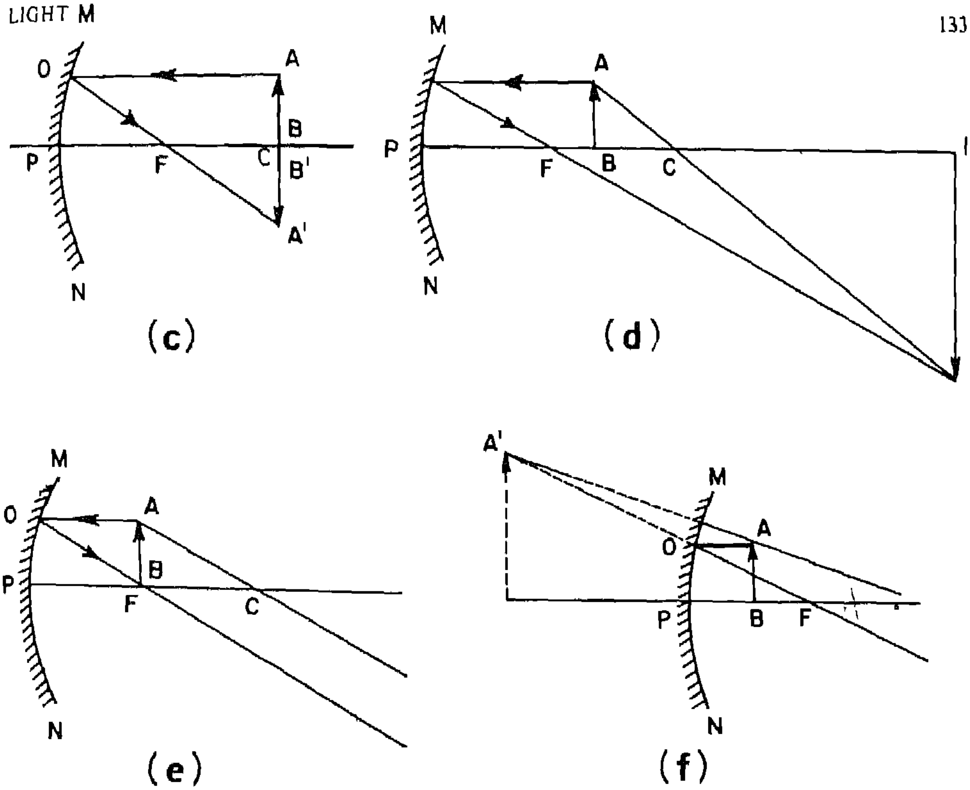


Fig. 13.1 *The position and the nature of the image formed by a convex mirror F is the focus, C the centre of curvature and P the pole of mirror. A B is the object and A' B' is image*

Table 13.1

IMAGE FORMED BY A CONCAVE MIRROR FOR DIFFERENT POSITIONS OF OBJECT

Sl. No	Position of the Object	Position of the Image	Nature and Size of the Image	Ray Diagram
1	At infinity	At the focus F	Real, very small and inverted	Fig 13 1(a)
2.	Beyond the centre of curvature C	Between F and C	Real, diminished in size and inverted	Fig 13 1(b)
3	At C	At C	Real, same size as object and inverted	Fig 13 1(c)
4.	Between F and C	Beyond C	Real, enlarged and inverted	Fig 13 1(d)
5.	At F	At infinity	Real, very large and inverted	Fig 13 1(e)
6	Between pole of the mirror P and focus F	Behind the mirror	Virtual, enlarged and erect	Fig 13 1(f)

13.2 Refraction by Spherical Lenses

In a similar way, we can determine the position, size and the nature of the image formed by spherical lenses by drawing ray diagrams. Table 13.2 provides details about the position, size and the nature of the image formed by a convex lens for different positions of the object. Figures 13.2 a-f illustrate the various situations.

Table 13.2

IMAGE FORMED BY A CONVEX LENS FOR VARIOUS POSITIONS OF OBJECT

Sl. No	*Position of the object*	*Position of of the image*	*Nature and size of the image*	*Ray Diagram*
1	At infinity	At focus F_1	Real, very small and inverted	Fig. 13.2(a)
2	Beyond 2 F_1	Between F_2 and 2 F_2	Real, diminished and inverted	Fig 13.2 (b)
3.	At 2 F_1	At 2 F_2	Real, same size and inverted	Fig 13.2 (c)
4	Between F_1 and 2 F_1	Beyond 2 F_2	Real, enlarged and inverted	Fig 13.2 (d)
5	At focus F_1	At infinity	Real, very large and inverted	Fig. 13.2(e)
6	Between F_1 and and the optic centre O of lens	On the same side of the lens	Virtual, enlarged and erect	Fig. 13.2(f)

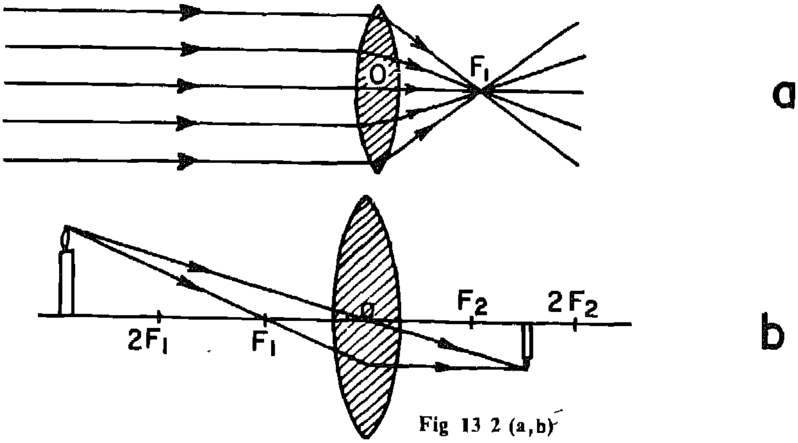


Fig 13.2 (a,b)

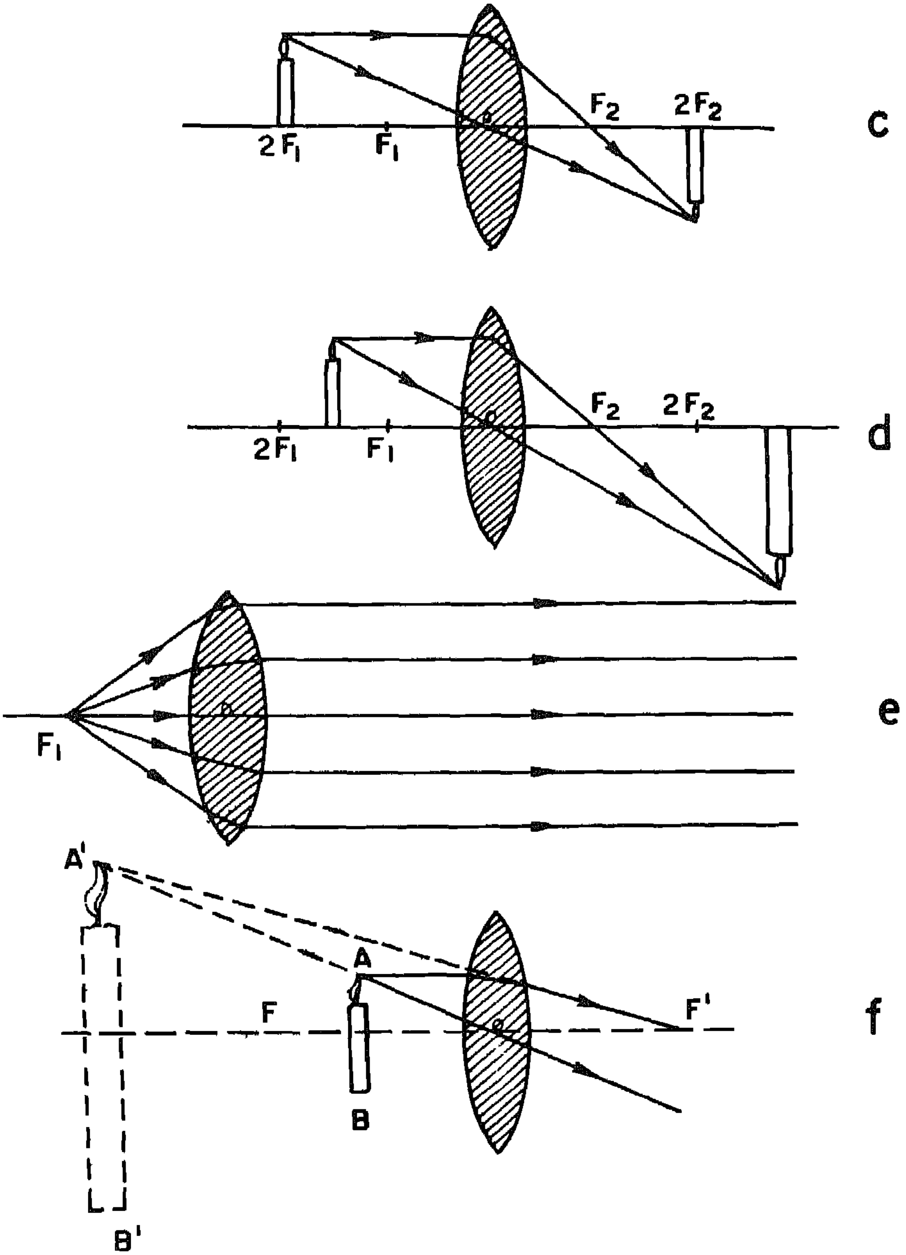


Fig.13.2 *The position and the nature of the image formed by a convex lens. AB is the object and A'B' the image F_1 and F_2 are two foci and O optic centre of the lens*

What about concave lenses? They spread apart parallel rays of light rather than focus them. The image a concave lens produces is always smaller than the object and is a virtual image. It is, however, an erect image as shown in Figure 13 3. Notice how the concave lens *diverges* the light beam while convex lenses *converge* the beam

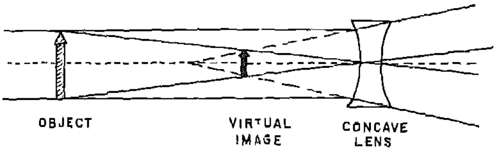


Fig 13 3 *A concave lens produces a virtual image of size smaller than the object*

13.3 Focal Lengths

We have been talking about the focal lengths of mirrors and lenses. How does one determine these focal lengths?

Activity 1

Take a concave mirror and focus the image of a far-off object such as the sun, a tree or a pole on a screen Measure the distance between the screen and the mirror This is the rough focal length, f, of the mirror

The same method may be used to determine the f value of a convex lens. Focus the sun sharply on the screen, using the lens The distance between the sharp image and the pole of the lens is f

With convex mirrors and concave lenses, one gets a virtual image that cannot be obtained on a screen We need a different method to measure their f values

A simple relation exists (Equation 13 1) between the focal length f, the distance of an object from the mirror u, and the distance of the image v from the mirror

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v} \qquad \text{(Equation 13.1)}$$

And the magnification M is given by the ratio

$$M=\frac{\text{Size of the image}}{\text{Size of the object}}=\frac{I}{O}=\frac{v}{u}$$

(Equation 13 2)

Different sign conventions are adopted for the measurement of u, v and f In this book, we shall follow the sign convention in which all distances are measured from the pole of the mirror The distances measured in the same direction as the incident light are taken as positive The distances measured in the direction opposite to the direction of incident light are taken as negative Let us now do an exercise

Exercise 1 An object 2 cm high is placed 20 cm from a concave mirror A real and inverted image falls at 40 cm from the mirror Draw a ray diagram using a graph paper and scale Calculate f and M

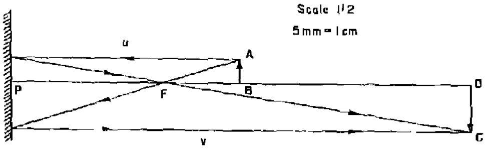


Fig. 13 4 *Scale diagram of reflection of A B by the concave mirror*

We have drawn the scale diagram of the reflection in Figure 13 4. The mirror is shown vertical for convenience We can directly measure v and the height I of the image CD from the graph, remembering the scale of 1:2 or 5 mm in the graph = 1 cm in the exercise It can be seen that here u,v and f are negative. We then get v = −40 cm and CD = I = 4 cm and f = −13.3 cm We can also get f and M using Equations 13.1 and 13.2 as·

$$\frac{1}{f} = \frac{1}{-20} + \frac{1}{-40} = \frac{-3}{40}$$

or $f = \frac{-40}{3} = -13.3$ cm

$M = I/O = v/u$

$I = \frac{v}{u} \times O = \frac{-40}{-20} \times 2 = 4$ cm

$M = \frac{4}{2} = 2$ Magnification is 2-fold

A similar formulae for f and M apply for lenses as well. For lenses

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \text{ and } M = \frac{v}{u}$$

Here too, the distances are measured, following a similar sign convention except that all measurements are taken from the optic centre of the lens

With lenses, one also defines a term called the *power*. The power measures the degree of divergence or convergence and is measured in *dioptres* or D The power is related to the focal length f (in cm) as $D = \frac{100}{f}$ For a lens of f = 50 cm, the power is +2. A lens of power −1.5 has a focal length of −100/1.5 = −66.6 cm The negative sign denotes divergence or a concave lens, the positive sign is for convergence and a convex lens. When we talk about the power of the lenses of the spectacles or eye-glasses, we do so in terms of their dioptres

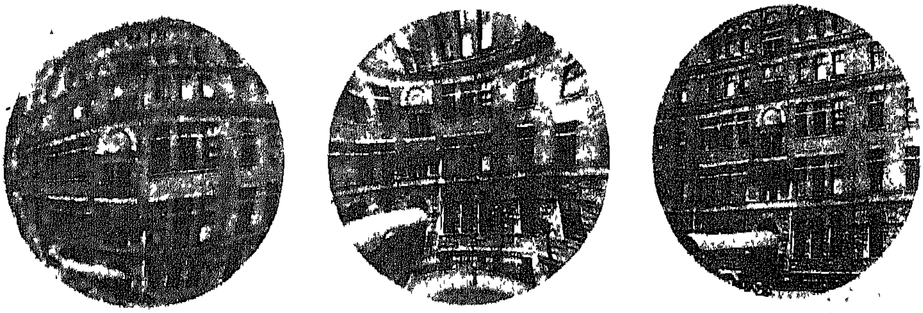


Fig. 13.5 *Anastigmat lens systems correct spherical oberration. The left and the centre are uncorrected*

13.4 The Camera and the Eye

A camera uses lenses to focus light rays on a film. It thus uses convex lenses so that the image can fall on the film. The sharpness of the image depends on the opening of the diaphragm (or the aperture as it is called).
When the diaphragm is opened wider to admit more light, the image can become less sharp This occurs because the edges of the lens may not focus the light to the same point as the centre does This defect is called *spherical aberration* and is corrected by using specially made meniscus lenses or by cementing together lenses made of different types of glass, called *anastigmat* lenses. Figure 13.5 shows how spherical aberration can be a nuisance and how anastigmat lenses correct it.

The human eye too is a similar optical instrument Its lens is a transparent structure made of proteins The focussed image falls on a screen behind the lens, called the *retina*.The retina sends electrical signals to the brain through the optic nerve so that we perceive images

The *cornea* is a transparent spherical structure that refracts light into the eye. The *iris* is a dark muscular assembly that controls the size of the *pupil*, the opening that regulates the amount of light entering the eye. When the light is very bright, the pupil becomes very small, while in a dim light it opens up fully through the relaxing of the iris The light through the cornea and pupil falls on the lens which focusses it on the retinal screen. The retina has an enormous number of light-sensitive cells. These get activated upon illumination and generate electrical signals that are sent to the brain through the optic nerves The brain interprets these signals as the sense of light. Figure 13 6 shows the details of the eye and its focussing set-up

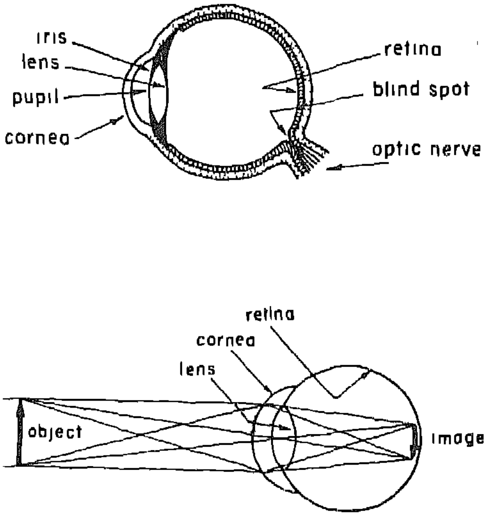


Fig 13.6 *(a) The human eye and its parts, (b) The focussing of an object and image formation in the eye*

There are of course very important differences between our eye and a camera. The image on the retina is not permanent but fades away after 1/20th of a second and overlaps with the next image This gives the impression of continuity. There is of course no film in the eye that records the images permanently as a photo film does. More importantly, the focal length of the eye lens is changed when its attached cilial muscles change their tension. When they are relaxed, the lens is thin and you can see distant objects clearly. When you are looking at nearby objects, the muscles compress the lens so as to decrease its focal length This property of the eye lens of changing its focal length is called its *power of accommodation*

However, the focal length of the eye lens cannot be decreased below a certain limit Try to read this book by holding it close to your eyes You may find that it strains your eyes To read the book comfortably you have to hold it at about 25 cm from your eyes This minimum distance at which one can see objects distinctly is called the *distance of distinct vision.*

13 5 Defects of Vision

Sometimes the eye loses its power of accommodation. When this happens one cannot see objects clearly, and vision becomes blurred.

In one kind of such a defect, one can see nearby objects clearly but it is difficult to see objects at long distances. In such a defective eye the image of distant objects is formed *in front of* the retina (Fig 13 7 a) and not at the retina This defect of the eye is known as *shortsightedness* or *myopia*, and it can be corrected by using a concave (divergent) lens (Figure 13 7(b). A concave lens of appropriate focal length brings the image back on the retina. In another type of defect, distant objects are seen clearly whereas nearby objects look blurred. In this case the image is formed *behind* the retina (Fig. 13.8 a). This defect is known as *longsightedness* or *hypermetropia.* It can be corrected by using a convex lens of appropriate focal length (Figure 13 8 b).

Sometimes a person may suffer from both myopia and hypermetropia. Such people often use bifocal lenses, in which one part of the lens acts as a concave lens and the other part as a convex lens. The third type of defect of vision is called *astigmatism.* This is somewhat similar to spherical aberration that we discussed earlier Here again corrective lenses are used to restore proper vision.

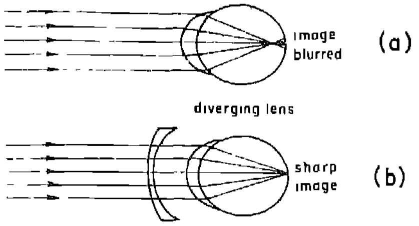


Fig 13 7 *(a) Shortsightedness (b) its correction*

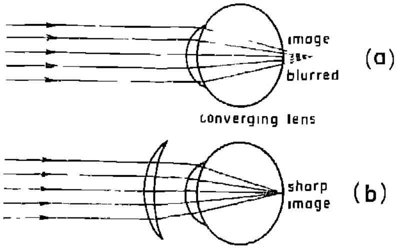


Fig 13 8 *(a) Longsightedness (b) its correction*

The normal eye cannot see very small objects like bacteria, cells and viruses. Similarly, the finer details of distant objects cannot be seen by the normal eye. For example, one cannot, from a large distance distinguish between the individual leaves of a tree. But the range of vision of the normal eye can be extended with the help of optical instruments like microscopes and telescopes.

13.6 Microscopes and Telescopes

These are magnifying devices. The microscope is used to magnify the size of objects that are too small to be seen by the "naked" eye, such as bacteria and cells. A telescope is used to "bring nearer" very distant objects such as ships, or the moon, the planets and the stars.

These instruments use two lens systems The first one, called the *objective*, forms the image of the object, the second lens system, called the *eye-piece*, takes this image and forms its image in turn. It is the latter that we see through the instrument. The objective is a lens or a system of lenses which acts as a converging (convex) lens In a microscope, object to be viewed is kept at a distance slightly larger than the focal length of the objective (as in Figure 13.2d) The objective forms an inverted, magnified and real image of the object.

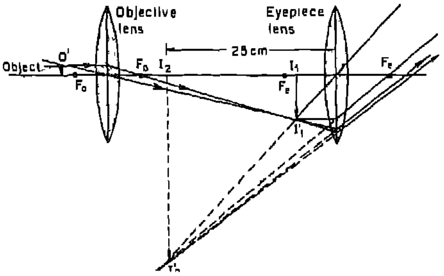


Fig 13 9 *Optical diagram of a microscope*

The eye-piece is also a system of convex lenses It is fixed in such a way that the image formed by the objective lens lies between the eye-piece and its focus This image acts as the object for the eye-piece which forms a further magnified but virtual image of the object. It is this image that we observe when we look into a slide through a microscope (Figure 13.9). The final image seen remains inverted with respect to the object.

The objective and the eye-piece of a microscope are mounted at the ends of a tube. The mounting is done in such a way that their axes are common. The power of magnification of the microscope is the ratio of the size of the image to that of the object The value of the magnification is given by

$$M = \frac{D \times L}{F_e \times F_o} \qquad \text{(Equation 13.3)}$$

Where D is the distance of distinct vision (25 cm as mentioned earlier), L the length of the microscope tube, F_e and F_o the focal lengths of the eye-piece and objective respectively, in centimetres Today a microscope with magnification of 5000 or more are available.

In a telescope, the objective and the eye-piece are similarly mounted. The focal length of the objective of the telescope is comparatively larger than that of a microscope The objective forms a real,

Fig 3.10 *Galileo Galilei*

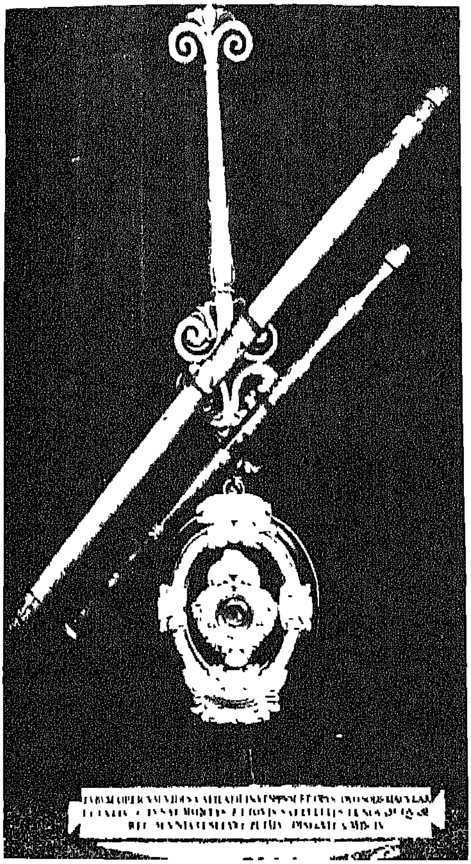


Fig. 13.11 *The telescopes used by Galileo*

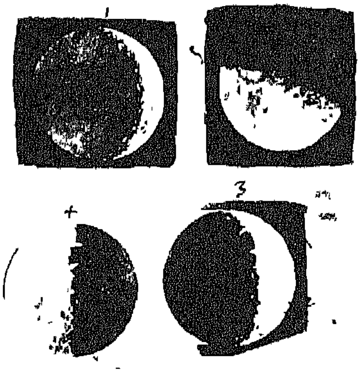


Fig. 13.12 *The pictures that Galileo drew of the phases of the moon that he saw through the telescope (Figs 13.10, 13.11 and 13.12, are taken from J. Bronowhle "The Ascent of Man")*

diminished-in-size and inverted image of a distant object at its focus as in Figure 13.2a. The position of the eye-piece is so adjusted that this image is formed between the optical centre of the eye-piece and its focus. The eye-piece then forms the final image which is virtual, enlarged and erect as in Figure 13.2f. Note that the final image is still inverted with respect to the object. This type of telescope is known as an astronomical telescope, and is used to study celestial objects. There, it is immaterial whether the final image is inverted or erect. In terrestrial telescopes, one more lens is used to invert the final image into the erect form.

The first use of the telescope for research was by Galileo Galilei of Italy in 1609. Figures 13.10, 13.11 and 13.12 show a portrait of Galileo, his telescopes and his own drawings of the phases of the moon, that he saw in 1610. He recorded all his findings in a book called *The Starry Messenger* where he describes the moon seen through the telescope thus: "It is a most beautiful and delightful sight to behold the body of the moon .. (It) does not possess a smooth and polished surface, but one rough and uneven and, just like the face of the earth itself, is everywhere, full of vast protruberances, deep chasms and sinuosities."

He used the telescope to discover four moons of Jupiter, the moons of Saturn and many stars.

13 7 Splendid Colours and White Light

The rainbow in the sky, the red glow of the sunset and the bright colours of flowers make us marvel at the beauty of nature and the complexity of light. How did the "white" light of the sun get broken up into the seven colours of the rainbow? The answer lies in the scattering of light by substances We can appreciate this by conducting two experiments that Sir Isaac Newton first conducted in 1666

Activity 2

Take a glass prism and allow a narrow beam of bright light (sunlight or a torch) to fall on one face Let the light emerging out of the other face fall on a screen or a wall (Figure 13 13) The white incident light is seen to be split into the famous VIBGYOR seven-colour patch, the splitting of light into its components is called *dispersion* The spread-out patch on the screen is the *spectrum*, which means a mixture of colours. Dispersion occurs because the refraction of different colours is different Violet is refracted most, and red least.

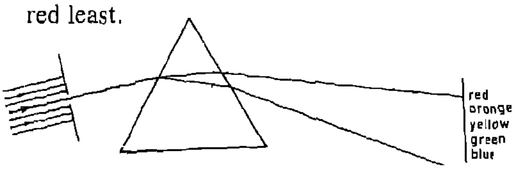


Fig 13.13 *Dispersion of "white" light by the prism*

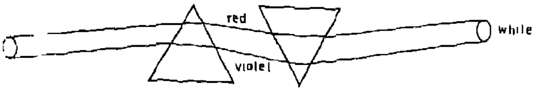


Fig 13.14 *The first prism disperses the white light into colours, while the second prism placed upside down recomposes them into white*

Activity 3

This needs a second prism, which should be placed upside down as shown in Figure 13.14 The second position receives all the dispersed rays from the first prism and re-composes them into the original beam The original beam of "white light", as Newton called it, is thus many-coloured or *polychromatic* and can be disposed into components of single colour *(monochromatic)* rays Each of these will have a specific wavelength and energy

Activity 4

You will need a torch light, and transparent glass sheets, plastic sheets or paper of green and red colours These are the kinds that will produce green and red light when the torch is lit behind them. First, produce red light Place a red object in the path It will appear red. Now produce green light and illuminate it on the same red object. The object will now appear black Examine a blue-coloured object in green light, and in red light It appears black in both cases Why?

The colour of an object depends on the wavelength of the light falling on it When white light falls on a coloured object, a part of the light is absorbed Whatever part is reflected from the object is its colour A red object absorbs all other colours of the spectrum and reflects red If a red object is illuminated with green light, it absorbs it and reflects none Hence it appears black in green light. Why does the blue object appear black in both green and red light?

The answer lies in what is called primary colours. Red, green and blue are the three primary or basic colours. Mixing them in various proportions gives us the other colours How is this so?

Activity 5

Take three torches Cover the glass of one with red cellophane paper, another with blue and the third with green Set up the torches in a darkened room so that their beams overlap. Now project all three coloured lights on a screen or the wall You will see the colours overlap as shown in Figure 13 15 and produce new shades.

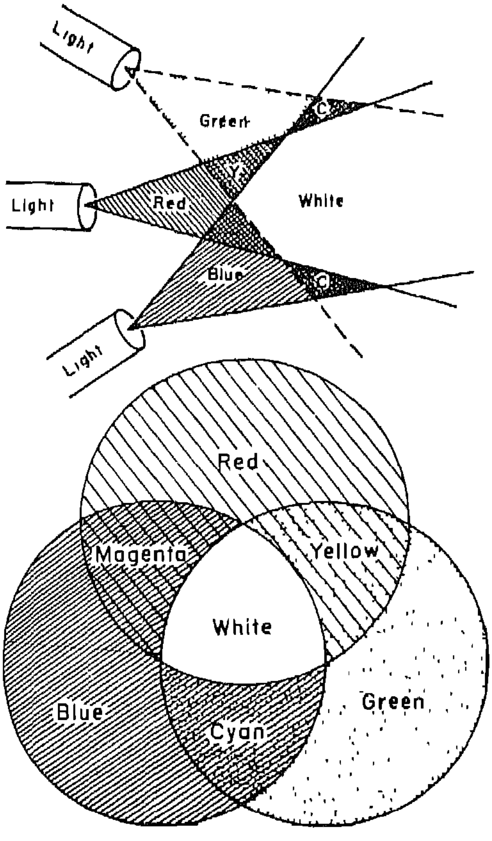


Fig 13.15 *(a) Overlap of colours from the three sources, (b) magenta, cyan and yellow are composite colours.*

Red + blue = magenta,
Blue + green = Cyan or peacock blue,
Red + green = Yellow

Mixing the three primary colours in various ratios gives the entire spectrum of colours This is what many of you did in nursery school and painters often do in their work

13 8 How Do We See Colours?

Our retina has a large number of light-sensitive cells These cells are of two shapes, rods and cones The rod-shaped cells respond to the intensity of light, that is the degree of brightness and darkness The cones respond to colours and it is the cones that make colour perception possible

Some people do not possess some cone cells that respond to certain colours. This defect occurs by inheritance, that is, it is a genetic disorder that cannot be cured as of today These people are said to be colour-blind They can see well otherwise, their only problem is the lack of ability to distinguish colours

SOME INTERESTING INFORMATION

1 John Dalton, founder of the atomic theory, was colour-blind and could not distinguish even between primary colours. As a result, this condition of colour blindness was known in the medical profession for quite some time as Daltonism.
2. Animals differ in their colour perception. The bee has retinal cone cells that enble it to see

colours beyond indigo and violet, namely ultraviolet. We human beings are ultraviolet blind.

3. The chicken eye retina has mostly cones and very few rod-shaped cells. The chicken therefore needs bright light to see; that is why it wakes up with the sun, and roosts by sundown
4. Some scientists think that the human eye is more like a TV camera than an ordinary camera. Do you know why?

IN THE LANGUAGE OF MATHEMATICS

If we denote:

f = the focal length

u = the distance of the object from the mirror or the lens

v = the distance of the image from the mirror or the lens

O = the size of the object (say, height)

I = the size of the image

M = magnification, D = dioptre

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \text{ (for spherical mirrors)}$$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \text{ (for spherical lenses)}$$

$$M = I/O = v/u$$

$$D = 100/f$$

and L = length of the microscope tube

if F_e = focal length of the eye-piece

F_o = focal length of the objective

D = distance of distinct vision

$$M = \frac{L.D}{F_e.F_0}$$

QUESTIONS

Choose the right answer.

1. The image formed by a concave mirror is seen to be virtual, erect and larger than the object The position of the object must then be
   (a) between the mirror and its focus
   (b) between the focus and the centre of curvature
   (c) at the centre of curvature
   (d) beyond the centre of curvature
2. Where should an object be placed so that a real and inverted image of the same size is obtained, using a convex lens?
   (a) Between the lens and its focus.
   (b) At the focus
   (c) At twice the focal length
   (d) At infinity.
3. The human eye forms the image of an object at its
   (a) cornea

(b) iris
(c) pupil
(d) retina

4 The beams of light, one red, and the other green fall on the same spot on a white screen The colour on the screen will appear to be
(a) magenta
(b) blue
(c) cyan
(d) yellow

5 The change in focal length of an eye lens to focus the image of objects at varying distances is done by the action of the
(a) pupil
(b) ciliary muscles
(c) retina.
(d) blind spot

6. How is the amount of light entering the eye controlled? What change is made in the eye to enable it to focus on objects situated at different distances?

7 What is shortsightedness, and longsightedness? How can these defects be corrected?

8 Why does it take some time to see objects in a dim room when you enter the room from bright sunlight outside?

9 If we need a magnification of 375 from a microscope of tube length 15 cm, and an objective of focal length 0 5 cm, what focal length of eye-piece should we use?

10. A diverging or concave lens of f= 15 cm forms an image 10 cm from the lens Draw a scale diagram and prove that the object is placed 30 cm away from the lens Use a scale of 1 5.

11. An object 5 cm high is held 25 cm away from a converging lens of f= 10 cm Draw a suitable scale diagram and find the position and size of the image formed. Is the image real or virtual?

CHAPTER 14

ELECTRICITY AND ITS EFFECTS

INTRODUCTION

ELECTRICITY IS one of the most convenient and important source of energy Electricity is used at home and in industry for various purposes, such as lighting, heating, operating machines and so on. In this chapter we study some basic ideas relating to electric current, and about the heating and magnetic effect of electric current

14 1 Potential Due to a Charge

Consider the process of depositing an electric charge, say, a positive charge on a body This is known as charging the body Initially the body had no charge on it; it now acquires a small amount of charge If you wish to deposit some more charge of the same kind on that body, this charge will experience a force of repulsion, due to the charges already present on the body Therefore, some work has to be done to counter this force of repulsion You know that whenever a body is raisd above the ground, some work has to be done to counter the force of gravity This work done on the body gets stored as its potential energy Similarly, the work done on the electrical charge in the process of charging gets stored as potential energy of charges We call this potential energy *electrostatic potential* or just potential

The electrostatic potential at any point is defined as the work done in bringing a single positive charge from infinity to that point. The unit of potential is the *volt* and has the symbol V

A potential of one volt at a point implies that the amount of work done to bring one coulomb of positive charge from infinity to that point is one joule

Thus if a body is given Q coulomb of charge to raise its potential by V volt, then the amount of work done will be VQ joule.

$$W = VQ \qquad \text{(Equation 14.1)}$$

14 2 Electric Current

If we place two objects, say electroscopes, charged to different potential side by side, charges will not move from one to the other Now if the two are connected, using a wire or a conductor, the flow of charges takes place Charge will flow as long as there is a difference of potential between the two The flow stops as soon as their potentials become equal *This flow of electric charge is called electric current* The potential difference (p d) of one volt between two points is the measure of work done in moving one coulomb of charge across them

$$\text{p.d.} = \frac{\text{work done}}{\text{charge moved}} = \frac{W}{Q} = \frac{\text{joule}}{\text{coulomb}}$$

$$= \text{volt} \qquad \text{(Equation 14 2)}$$

The simplest way of maintaining a potential difference between the two ends of a conductor is to connect it to a battery or a dry cell (Figure 14 1) A cell or a battery does so because a difference in potential between its two electrodes is maintained by the chemical processes going on inside it, between its electrodes and the electrolyte The arrangement for obtaining electric current in a conductor by connecting it to a source of electric current is an example of a simple *electric circuit*

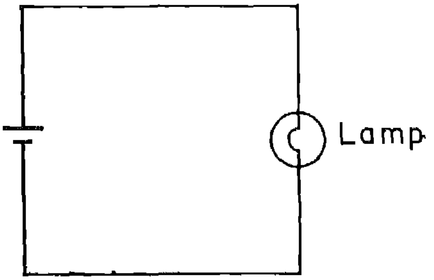


Fig. 14 1 *A simple electric circuit*

The magnitude of the current I is the charge flowing in the circuit in one second

$$I = \frac{Q}{t} = \frac{\text{charge}}{\text{time}} \qquad \text{(Equation 14.3)}$$

Where Q is the charge in coulomb flowing in t second. If one coulomb of charge flows through the circuit in one second, the current in the circuit will be 1 *ampere*, which is the unit of current

Work done when a charge flows across a p d. = Electrical energy involved = $VQ = VIt$

(Equation 14 4)

The device used for measuring current in a circuit is called an *ammeter* It is always connected in a manner that all the current in the circuit flows through it. The ammeter thus becomes an essential part of the circuit in which it is joined (Figure 14 2)

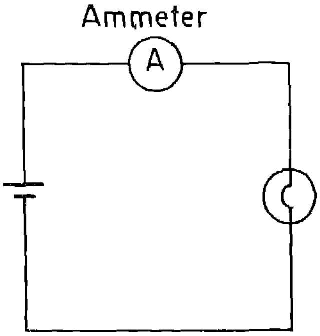


Fig. 14.2 *An ammeter connected in circuit*

The device used for measuring potential difference between two points is known as a *voltmeter.* In contrast to an ammeter, a voltmeter is joined as an addition to an already completed circuit. Figure 14 3 shows how a voltmeter is connected to measure the potential difference across a lamp Note the language used to describe the action of two meters an ammeter measures current *through* a component, while a voltmeter measures potential difference *across* a component The manner in which an ammeter is joined in a circuit is called a *series connection* while a voltmeter is in *parallel connection.*

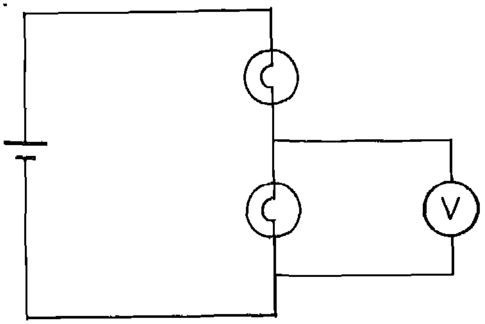


Fig. 14.3 *A Voltmeter is connected across a component in order to measure its potential difference In contrast, an ammeter is joined in a series connection*

INSIDE A WIRE

Inside a wire, electrons normally drift about in all directions between the atoms of the metal (See Figure 14 4a) When the wire is connected to a source of electricity, the electrons begin to move in one direction and an electric current flows along the wire (Figure 14.4b)

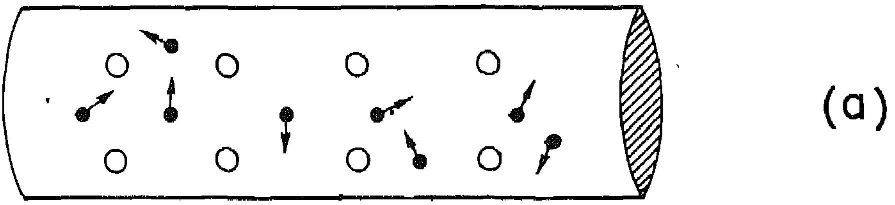


Fig 14.4 a *A random, motion of electrons in metal wire Big circles are atoms and small filled ones are electrons*

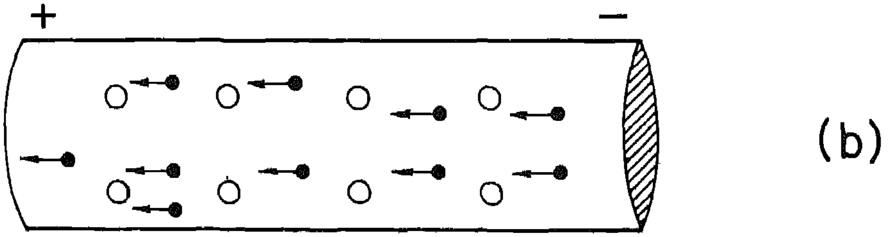


Fig. 14.4 b *Electrons now move in the specific direction towards the positive pole, when electricity is passed along the wire*

Conventionally, the direction of current is taken as the direction of flow of a *positive* charge Therefore, in an electric circuit the direction of current is always taken as *opposite* to the direction of the flow of electrons Any point in the circuit which is at a higher potential for electrons is regarded as a lower potential for current, and is marked negative Similarly, any point which is at a lower potential for electrons is regarded as a higher potential for the current in a circuit and is marked positive.

14 3 **Ohm's Law—Resistance**

Activity 1

Figure 14 5 shows a circuit to study the variation of electric current through a wire AB due to variations in potential difference A nichrome or eureka wire of about 50 cm length may be used for the purpose of the study The potential difference may be varied by using several dry cells of 1 5 volt each Set up the circuit as shown in Figure 14.5 by connecting only one cell at first Note the current I in the circuit and potential difference V across the wire AB Next connect first 2 cells, then 3 cells and then 4 cells in series in the circuit. Note the current and potential difference in each case For each pair of readings, calculate the ratio between the p.d. V and current I. You will find that you get about the same value for this ratio

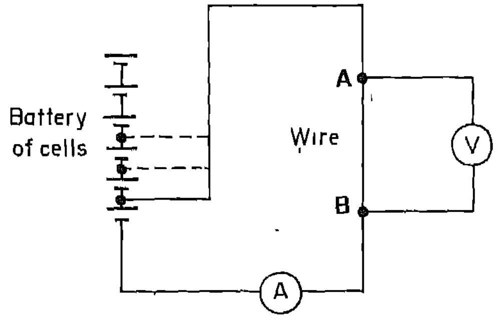


Fig. 14 5 *A circuit to measure resistance of wire AB*

Now plot a graph between current and the potential difference You will obtain a straight line graph as shown in Figure 14.6 This indicates a direct proportion between the quantities involved That is

$$V = (\text{constant}) \times I \qquad \text{(Equation 14.1)}$$

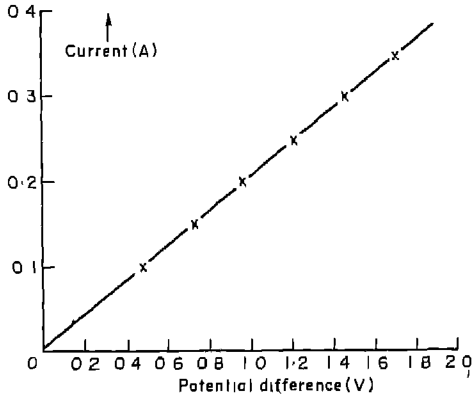


Fig. 14.6 *Voltage changes linearly with respect to current This is the graphical representation of Ohm's law*

Activity 2

Connect a battery of four dry cells each of 1 5 volt with an ammeter, leaving a gap in the circuit as shown in Figure 14 7. Complete the circuit by connecting in the gap one after the other a torch bulb, a 15 watt bulb, a thick strip of copper and a piece of nichrome wire. (The copper strip should be connected only for a fraction of a second) Note the current in the ammeter in each case You

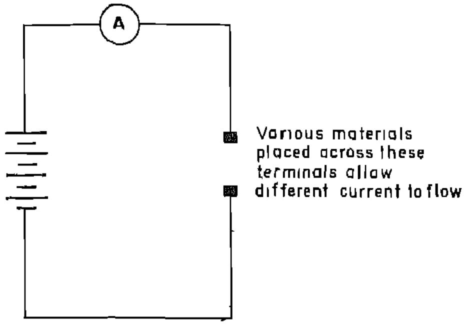

A
Various materials placed across these terminals allow different current to flow

Fig. 14.7 *Various materials placed across the terminals allows different amounts of current to flow*

will find that the current through the circuit varies over a wide range. Why? The current through the circuit is not decided by the battery. It is the components in the circuit which determine how much current they will draw from a given battery. Some materials allow larger current to flow through them than others. In other words, certain materials offer more *resistance* to the flow of current than others. The property of a material due to which it opposes or limits the flow of electric current through it, is called its *electric resistance* or just resistance.

The resistance of a conductor may be defined in terms of current passing through it and the potential difference across its ends. The resistance is defined as the ratio of potential difference V across its ends and the current I flowing through it. That is, resistance

$$R = \frac{V}{I} \qquad \text{(Equation 14.6)}$$

Since the unit of potential difference is volt and that of current ampere, the unit of resistance is $\frac{\text{volt}}{\text{ampere}}$. The unit of resistance is called the *ohm*, named after George Simon Ohm, who discovered the relations 14.5 and 14.6. Ohm's law states that the current in a circuit is proportional to the voltage across it. It also states that the resistance in a circuit is the ratio of the voltage to its current. One ohm is the resistance of a conductor through which a current of 1 ampere flows when the potential difference across its ends is 1 volt.

The resistance of a material plays an important role in electric circuits. The parts or components of the circuit which are to provide a path for the movement of charges are made from materials with low resistance. These are usually referred to as conductors. Often some parts or components of the circuit are intentionally designed to offer high resistance. These are made from materials with a high resistance which are called *resistors*. A substance that has infinitely high resistance will not allow electricity to flow through. It is called an *insulator*. Rubber is an excellent insulator.

14.4 An Electric Circuit Transfers Energy

A potential difference is a measure of work done in moving a unit of charge across a circuit (Equations 14.1 and 14.2). You also know that the current in a circuit is equal to the amount of charge flowing in one second (Equation 14.3). Thus

Work done = potential difference × current × time

or

$$W = VIt$$

where W is work done, V potential

difference, I current and t the time. From the definition of resistance you have V = I R (Equation 14.6). Therefore, the work done

$W = I^2 Rt$ (Equation 14.7)

The work done in moving the electric charges across a resistor often appears in the form of heat. If a current of I ampere flows through a resistor of resistance R ohm for t seconds it will produce heat equivalent to $I^2 Rt$ joule.

Hence the heat produced is directly proportional to the resistance, to time and to the square of the current. Thus, in an electric circuit with a resistance the electric energy gets converted into heat. This is known as the heating effect of electric current.

The heating effect of electric current is made use of in all electrical heating devices like electric bulbs, heaters, iron, immersion heaters, and cooking ranges.

14.5 Electrical Power

Power is the rate at which work is done. In an electric circuit, the work done in a time t is given by Equation 14.4. Therefore,

$$\text{Power } P = \frac{W}{t} = VI \qquad \text{(Equation 14.8)}$$

If p.d. is measured in volt and current in ampere, the unit of power is a *volt ampere,* also called a *watt.*

$$1\,\text{volt} \times \text{ampere} = \frac{1\,\text{joule}}{1\,\text{coulomb}} \times \frac{1\,\text{coulomb}}{1\,\text{second}}$$

$$= \frac{1\,\text{joule}}{1\,\text{second}} = 1\,\text{watt}$$

Thus a unit of electric power is *watt.* Electric power is the rate at which energy is consumed by the circuit. If an appliance of 1000 watt, that is, one kilowatt or kW is connected to the circuit, it will consume 1 kJ of electric energy in one second. A convenient unit to measure electric power used is the kilowatt hour or kWh. This is often simply called a unit.

$$1\,\text{kWh} = 1000\,\text{watt} \times 3600\,\text{second}$$
$$= 3.6 \times 10^6\,\text{watt second}$$
$$= 3.6 \times 10^6\,\text{joule}$$

Exercise 1

In a house two 60 watt electric bulbs are lighted for 4 hours, and three 100 watt bulbs for 5 hours everyday. Calculate the electric energy consumed in 30 days.

Energy consumed by two 60 W bulbs in

$$30\text{ days} = 2 \times \frac{60}{1000} \times 4 \times 30 = 14.4\,\text{kWh}$$

Energy consumed by three 100 W bulbs in 30 days

$$= 3 \times \frac{100}{1000} \times 5 \times 30\,\text{kWh} = 45\,\text{kWh}$$

Total energy consumed in 30 days
= (14.4 + 45) kWh = 59.4 kWh

Exercise 2

An electric heater draws a current of 10 A from a 220 V supply. What is the cost of using the heater for 5 hours everyday for 30 days if the cost of 1 unit (1 kWh) is 60 paise?

I = 10 A, V = 220 V
Time = 5 × 30 = 150 hours
Electric energy consumed = VIt

$$= 220\,\text{V} \times 10\,\text{A} \times 150\,\text{h}$$
$$= 330000\,\text{watt hour}$$
$$= 330\,\text{kilowatt hour}$$

Cost of 1 kilowatt hour = 60 paise
= 0 6 rupee

Cost of energy consumed = 330 × 0.6
= Rs 196 00

Electrical Heating Devices

The heating effect of an electric current is used in many devices like heaters, boilers, irons, toasters and so on The basic principle in these is the use of resistors A water heater may have a resistance of 20 ohm Upon passing a current this can generate sufficient heat to boil water, as Exercise 3 shows

Exercise 3

An immersion heating rod of 2 kW and 220 volt rating is used to heat a bucket containing 15 litres of water If the initial temperature of the water was 20°C, what would the temperature be after heating with this rod for 15 minutes? The specific heat of water is 4200 J/kg/°C

$$
\begin{aligned}
\text{Energy } E = P \times t &= 2000\ \text{W} \times 15\ \text{min} \\
&= 2000 \times 15 \times 60\ \text{W second} \\
&= 1.8 \times 10^6\ \text{watt second} \\
&= 1.8 \times 10^6\ \text{joule}
\end{aligned}
$$

(since 1 J = 1 W s)

Heat gained by the water =
mass × specific heat × $(T_2 - T_1)$

This should be equal to E So

$$1\,8 \times 10^6 = 15\text{kg} \times 4200 \frac{\text{J}}{\text{kg}\,^\circ\text{C}} \times (T_2 - T_1)^\circ\text{C}$$

$$(T_2 - T_1) = \frac{1\,8 \times 10^6}{15 \times 4.2 \times 10^3} = 28.6^\circ\text{C}$$

$$T_2 = T_1 + 28.6 = 20 + 28.6 = 48.6\ ^\circ\text{C}$$

This exercise also shows how electrical energy is transformed into heat and can be used to advantage.

14 6 Electromagnetism: Electricity Produces Magnetism

An important experiment by Hans Oersted showed that a compass needle gets deflected when an electric current is passed through it This is shown in Figure 14 8 This exciting discovery was followed up by others like Henry, Faraday and Maxwell. Maxwell showed that the magnetic lines of force around a straight wire have a definite direction

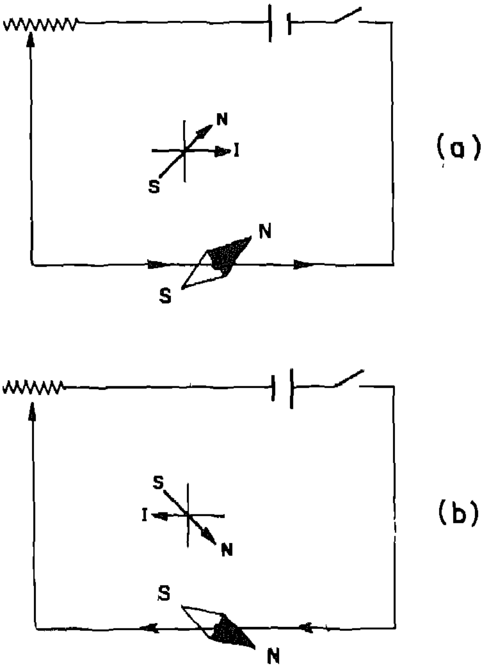


Fig. 14.8 *Generation of magnetic field by electric current· Oersted's experiment*

Activity 3

Set up the circuit as shown in Figure 14 9. Let the copper wire pass through a horizontal cardboard as shown. Using the rheostat, allow a current of 2 ampere through the circuit from the car battery.

Now place the compass needle in various positions on the cardboard around the wire. Mark the directions of the north pole, so that the lines of force are drawn Now reverse the current direction by interchanging the connections of the battery The needle will point in the opposite direction The mutual directions between the current and the magnetic field are shown by the *Maxwell right-hand grip rule* (Figure 14 10)

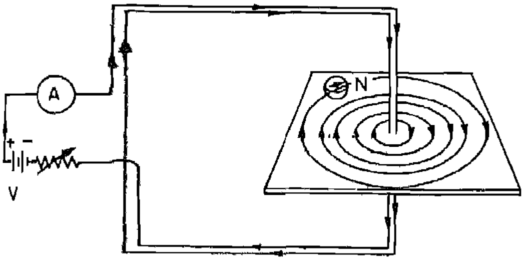


Fig. 14.9 *Electricity passing through a wire affects the deflection of the compass placed on the cardboard*

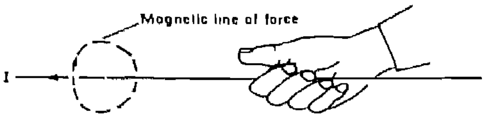


Fig. 14.10 *The Maxwell right-hand grip rule*

Activity 4

Change the configuration of the wire in Activity 3 to a circular coil The arrangement is now as shown in Figure 14 11. Rather than use a compass needle, use some iron powder or iron filings. Sprinkle some of these on the cardboard round the wire. Pass a current of 2-3 ampere and gently tap the cardboard The iron filings will get magnetised and arrange themselves in concentric circles around the wire as their centre

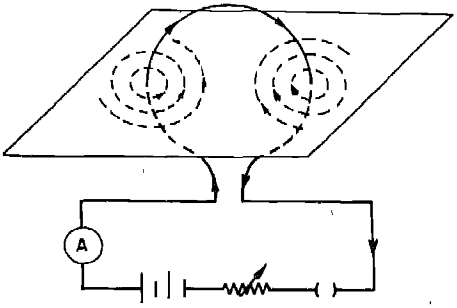


Fig 14.11 *Magnetisation of iron filings in concentric circles*

What would happen if a long cylindrical coil of wire, also called a solenoid, is used to pass the current? Look at Figure 14 12 Since the current in each circular loop has the same direction, their effects add up and we get a strong magnetic field. The direction of the magnetic field is given by the right-hand grip rule (Figure 14.10); but now the thumb is the north pole of the magnet while the current flows in the direction of the fingers

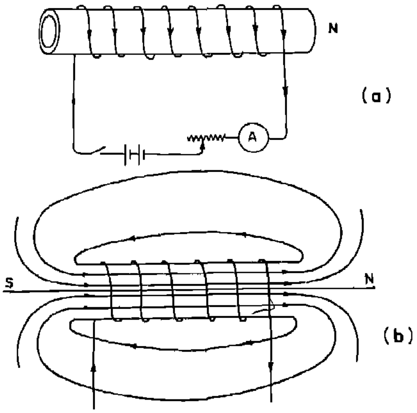


Fig. 14.12 *Magnetic field generated by passing electric current through a solenoid Notice that the solenoid acts like a bar magnet*

The solenoid material of the *core* is magnetised by the current The strength of the magnet will depend on (a) the number of turns in the coil, the larger the number the stronger the magnetism, (b) the strength of the current--the larger the current the stronger the field; and (c) the nature of the core material The core is an *electromagnet* When the current is switched off, the core loses its magnetism. This is particularly true when iron is used as the core

14.7 **Magnetism Affects Current**

Activity 5

Hang a thin aluminium rod (2 mm diameter and 5 cm long would be a good size) between the poles of a horseshoe magnet using springs as shown in Figure 14 13 Insulate the springs with rubber or plastic sheath so that they are not charged Connect the aluminium rod to a battery circuit as indicated. When the circuit is completed by using the key, the aluminium rod will be pulled down and the springs will stretch

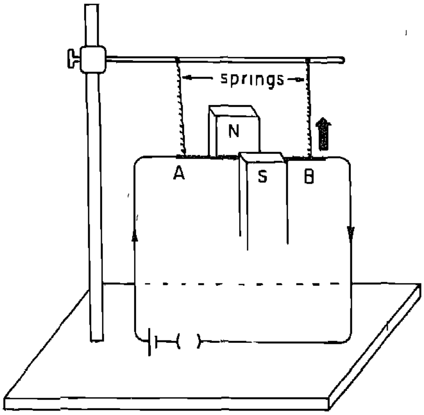


Fig. 14.13 a *Magnetic field across a current carrying conductor AB moves it*

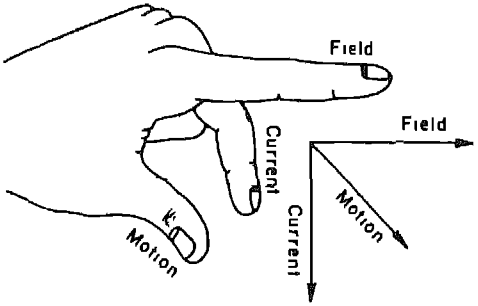


Fig. 14.13 b *Mutual orientation between the field, current and movement Fleming's left-hand thumb rule*

Now switch the direction of the current by reversing the battery The force on the rod will be the opposite of what was seen above Now, reverse the direction of the magnetic field The rod will move in the opposite direction.

A magnetic field exerts a force on a current-carrying (or *live*) material and causes it to move The mutual directions of the field (F), current (C) and the movement (M) are given by the directions of the *F*orefinger, se*C*ond finger and the thu*M*b of the left-hand (Figure 14 13 b) This rule, called the *left-hand thumb rule* was suggested by Professor J.A Fleming of England

14 8 **The Electric Motor**

We see that a current moves a magnet (Figure 14 8) because it itself generates a magnetic field (Figure 14.10). We also see that a magnetic field moves a live conductor (Figure 14 13) Michael Faraday showed that a rotational motion can be produced in a live conductor by a magnet. His experiment is shown in Figure 14 14 A movable wire is immersed in liquid mercury Upon passing current, the wire rotates round the magnet

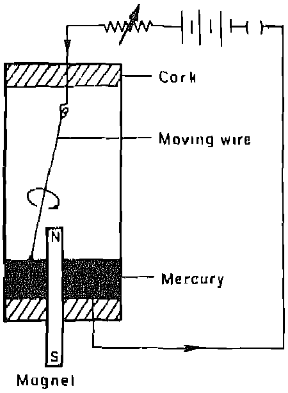


Fig. 14.14 *Faraday's experiment showing that a live conductor is rotated by a magnet*

Faraday's experiment illustrates the principle of an electric motor. In the modern design, (Fig. 14.15) a rectangular loop of wire ABCD is wound on an *armature*. The armature rotates around a spindle between the poles of a magnet.

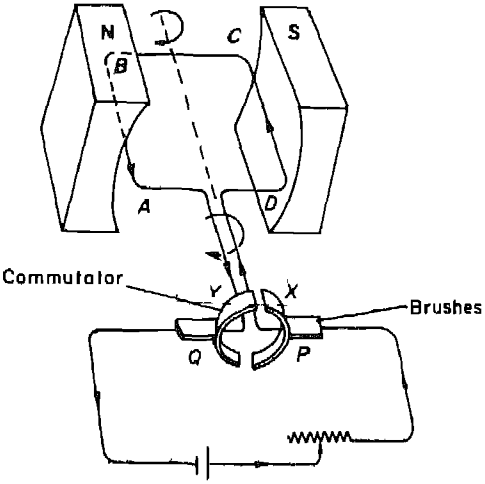


Fig. 14.15 *An electric motor*

The coil is connected to a split ring (the *commutator*). When current is passed through the coil loop, the magnetic field pushes CD down and AB up (the left-hand rule). This moves the coil clockwise. At half rotation, the polarity of the commutator changes since now it is Y which contacts the brush P and X contacts Q. This reversal pushes AB down and CD up. A continuous rotatory motion is produced and an electric motor is obtained.

14.9 Electromagnetic Induction—Magnetism Produces Electricity

We have seen the connections between a magnetic field, an electric current and the motion of the current-carrying conductor. Electricity produces motion in a magnet. Magnetism produces motion in a live conductor. Electricity produces magnetism in a moving coil. Can magnetism do the reverse? Can electricity be generated in a moving coil by a magnetic field? This question was posed and answered in the affirmative by Michael Faraday. The process is called electromagnetic induction and the current produced is called the induced current.

Electromagnetic induction is the opposite of the electric motor concept. Thus the relation between the magnetic field, the motion of the conductor and the direction of the current is not a left-hand rule, but a right-hand thumb rule. This mutual orientation is shown in Figure 14.16.

Figure 14.17 shows the diagram for the generation of electricity using this concept. It is thus the scheme for the electric generator. The core is rotated around the brushes and inside the magnetic field. With the rotation and the switching at the split rings, electric current is generated with X as the + and Y as the − poles.

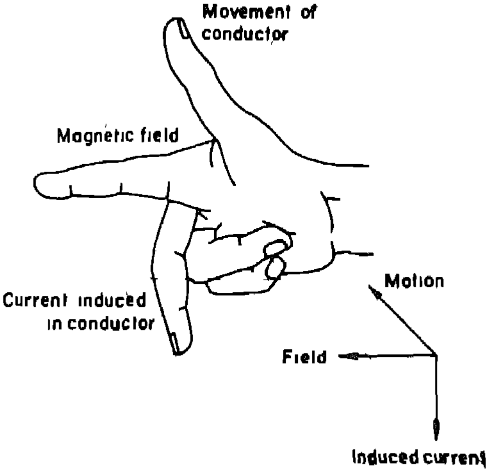


Fig 14.16 *The right-hand thumb rule in electromagnetic induction*

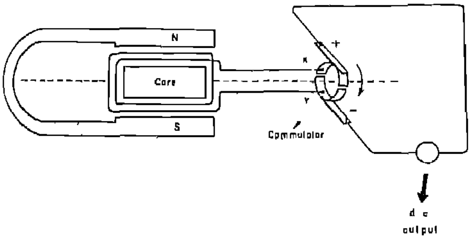


Fig 14 17 *The principle of the dynamo or the electric generator*

The current produced is called direct current or D.C. Rather than one split ring, if two slip rings are used, the current produced will change polarity at every half-rotation, or alternate in polarity. Such a current is called A C Such electric generators are called *dynamos* The bicycle dynamo is a D.C generator, as is a car dynamo. A.C. generators are more common in industry and electrical substations.

Electric Power Plants

This principle of the generator is used to produce large amounts of electricity in power plants and stations. The power produced may be a few kilowatts in diesel generator sets (gensets) or as high as a few hundred megawatts (mega = million) in atomic power plants or hydroelectric stations.

The coil or the core is fixed on a common shaft with a turbine (A turbine has a rotor with blades or vanes and is driven by the pressure of moving water, steam or air) When the turbine rotates, the core rotates with it and generates electricity In a hydel station, the flow of water runs the turbine In thermal and in atomic power plants, steam is produced at high pressure and used to rotate the turbine blades The fuel used in thermal stations to produce steam is coal or natural gas, while it is atomic nuclei in the atomic power plants (in diesel generator sets, the fuel is diesel oil and the motor is similar to an automobile engine Diesel gensets are used only in homes or in small buildings since even the largest one produces only about 75 kW.)

The electrical power produced by these major power plants is usually alternating current (AC) and the voltage may be 22000 V or above. This electricity is sent along transmission lines to users Figure 14 18 shows the manner in which electrical power is transmitted and distributed to users The grid sub-station often increases the voltage to as high as 1 megawatt by the use of transformers These high voltages help in reducing the loss of electrical energy during transmission. It is then reduced in steps at various substations and distributed to consumers

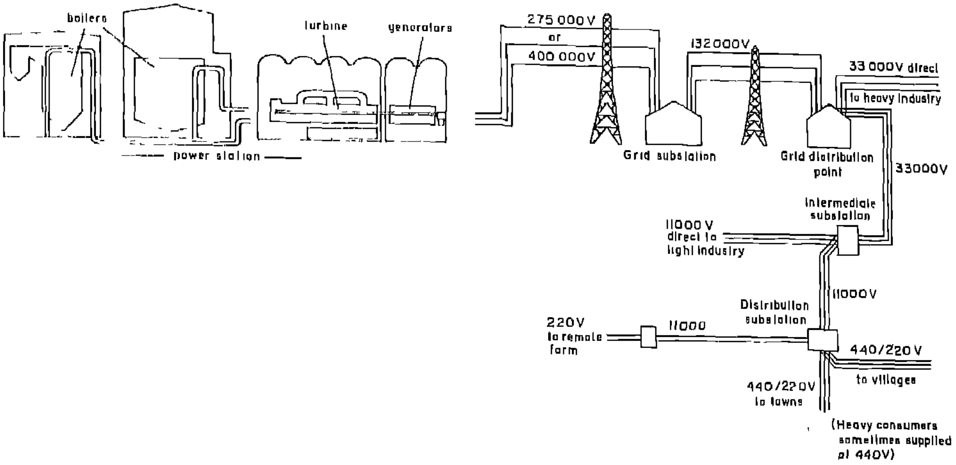


Fig. 14.18 A schematic diagram for generation and distribution of electricity

14.10 Electricity Used at Home

Electricity supplied to us at our homes is 220 volt and A.C, that is current alternating its polarity 50 times a second or 50 hertz (Hz). We call this main line power and the wires carrying it are called the mains. The mains may often bring two different ampereage supplies—5A and 15A. The former is called the "domestic" and the latter the "power line" The two ratings are important since we use a variety of appliances—bulbs and tubes, heaters, radios, TV sets, refrigerators and so on. Some of these need 5A power while others need 15A power

Why are two ratings used? The answer lies in the ratings of each appliance One appliance has a different resistance from the other and yet both need to be supplied with the proper voltage and current We illustrate a situation below.

Activity 6

Set up circuits as shown in Figure 14.19 In part (a) of the figure the three resistances R_1, R_2 and R_3 are connected in series In part (b) they are connected in parallel.

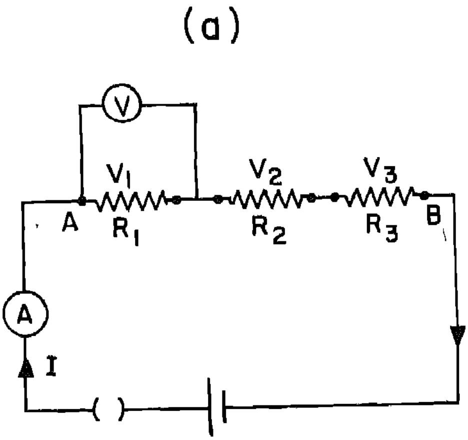


Fig. 14.19 a *Resistances in series*

First set up the circuit as in Figure 14.19a. The same current I will pass through each resistor since there is no other path Now measure the p d V_1 across R_1, V_2 across R_2 and V_3 across R_3 in turn Now connect the voltmeter across

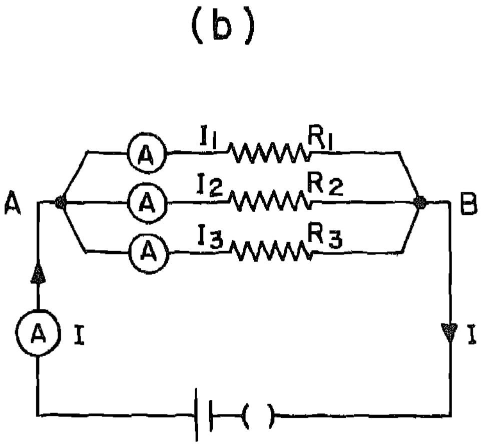


Fig. 14.19 b *Resistances in parallel*

AB, including all three resistors, and measure the p d V You will see that

$$V_1 + V_2 + V_3 = V$$

or by Ohm's law

$$IR_1 + IR_2 + IR_3 = IR$$

$$I(R_1 + R_2 + R_3) = IR$$

$$R_1 + R_2 + R_3 = R$$

(Equation 14 9)

The equivalent resistance R across AB is the sum of the three resistances connected in series

Now connect the circuit as shown in Figure 14 19b Since R_1, R_2 and R_3 are all connected in parallel across A and B, the p d V in each is the same as that on the equivalent resistance R. Upon measuring the currents, you will find that

$$I = I_1 + I_2 + I_3$$

or the current is divided up across the resistor.

By Ohm's law. $I_1 = V/R_1$, $I_2 = V/R_2$, $I_3 = V/R_3$; $I = V/R$

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{(Equation 14.10)}$$

A series circuit allows the current to flow through each connection in turn A series circuit increases the resistance as per Equation 14.9 The current is thus reduced accordingly.

A parallel circuit divides the current passing through the electrical connections The total resistance in a parallel circuit is decreased as per Equation 14 10. This is helpful particularly when each connection has a different resistance and a different current.

At home we use appliances of different resistances A heater has a resistance of bout 20-40 ohm while a bulb has a resistance twenty times higher If the two were in series, the flow of current would be reduced and each appliance may not get the appropriate power (I^2R) for its function. When connected in parallel, the total resistance is decreased and the ampereage increased. Each device gets the necessary energy

A heater of 2 kW and 24.2 ohm resistance will draw a current of 9 1A at 220 V (recall $P = VI = I^2R$) But a bulb of 100 W rating has a resistance of about 480 ohm and needs a current of 0.45A only The ratings of the two devices are very different and hence their needs. It is thus more convenient to provide two different main line powers—one of higher ampereage (15A) for use with heaters, cookers, irons, refrigerators and such heavy duty appliances, and the other of 5A rating for lighting and other light duty appliances.

Domestic Wiring

The mains supply is delivered to houses using a three-core wiring called the *live, neutral* and the *earth*. The live wire is red in colour and brings in the current. The neutral, coloured black, is the return wire. The earth is coloured green. These wires supply electricity to separate circuits within the house. Two separate circuits are used, one of 15A for appliances with higher power ratings and the other of 5A rating for others. The earth wire is usually connected to a metal plate deep in the earth near the house. It is a safety measure and does not in any way affect the supply.

Figure 14.20 shows different types of common domestic circuits. Within each separate circuit, appliances are connected across the live and neutral wires. Each appliance has a separate switch to control the flow of current to it. The switch is always connected in the live wire. One advantage of this method of wiring is that if one section is switched off it does not affect other sections. It also provides the same voltage to all the appliances connected to the circuit.

14.11 Fuse—A Safety Device

The wires used for electric circuit are chosen so as to allow a certain maximum current to pass through them. If the current exceeds this value, the wires may get overheated and cause a fire. The current in the circuit may increase beyond the permitted limits usually due to (i) overloading, and (ii) a short circuit.

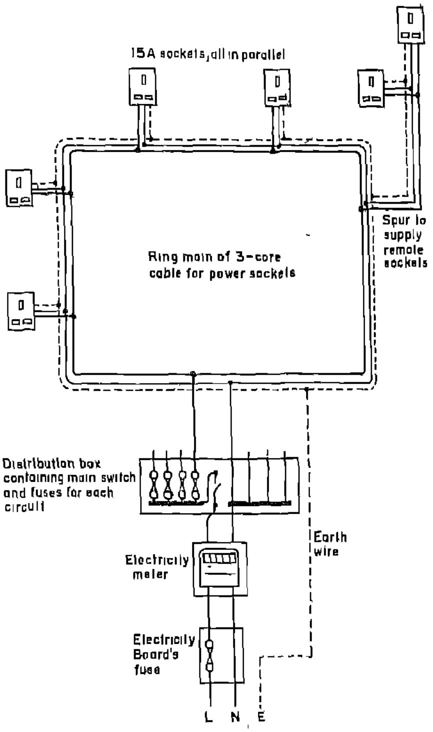

15A sockets, all in parallel
Spur to supply remote sockets
Ring main of 3-core cable for power sockets
Distribution box containing main switch and fuses for each circuit
Earth wire
Electricity meter
Electricity Board's fuse
L
N
E

Fig. 14.20 *A common domestic circuit*

The current in a circuit depends on the power rating of the appliances connected to it. The choice of wires depends upon the maximum current estimated to pass through them. If the total power rating of the appliances exceeds this permitted limit, they tend to draw a large current. This is known as overloading.

Sometimes, the live and neutral wires come in direct contact due to defective or damaged wiring. When this happens, the resistance of the circuit becomes almost zero and a very large current flows through it. This is known as a short circuit. As a result, wires may be overheated and appliances may get damaged.

Sparking at the point of a short circuit may also occur and cause a fire

Many precautions and safety measures are taken to protect the circuits against damage due to overloading or a short circuit. All wires used in an electric circuit are coated with a layer of insulating materials. In addition, they are covered by cloth, rubber or plastic layer As a result, ordinarily the wires do not come in direct contact and the short circuit does not occur Besides, division of circuits into different sections not only facilitates repair of each section independently, but also restricts the damage due to overloading or a short circuit

The most important safety device used for protection of electric circuits is the *fuse* (Figure 14 21) The fuse is a piece of wire of a material with a very low melting point. When a high current flows through the circuit due to overloading or a short circuit, the fuse wire gets heated and melts. As a result, the circuit is broken and current stops flowing. It must be remembered that a fuse is always connected to the live wire Good fuse wire is made of pure tin, but a cheaper variety is made of an alloy of tin and copper. The thickness and length of fuse wire depends on the maximum current permitted through the circuit For proper protection, it is essential that the fuse used is of correct value In a 15A circuit, the fuse wire used is thick and of 15A rating. In a 5A circuit, a thin fuse wire of 5A capacity is used.

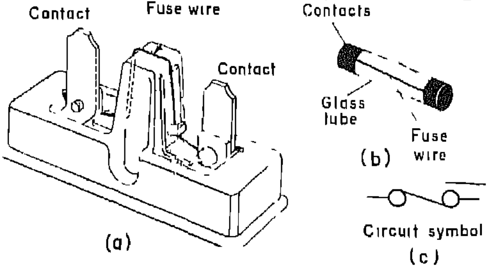


Fig 14 21 *Two types of electric fuse with their sockets*

14 12 Hazards of Electricity

Electricity is one of the most important and convenient sources of energy available to us However, it could be dangerous if certain precautions and safety measures are not observed while using

You know that if you touch any point of an electric circuit you get a shock. Sometimes these shocks are so severe that they may kill a person The flaws in electric circuits like loose connections, defective switches, damaged wires, short circuit or overloading can cause sparking or overheating and sometimes cause fires To avoid such hazards, safety devices and precautions are essential in handling electric circuits We have seen how a fuse acts as a safety device. Some other essential precautions to be observed are

1 The circuit must be immediately switched off in case of fire or any other accident.
2 All connections at switches, plugs and sockets, and junctions must be tight. All wiring should be of good quality, proper thickness and insulation Defective switches should be replaced immediately All joints should be covered with insulated tape
3 Whenever repairs are needed or any part of the circuit needs direct handling of any kind, rubber gloves and shoes must be used The testers, screw drivers,

pincers and other tools used for repairing should have proper insulation

4 The fuse should be of proper rating and material Often connecting wires are used as fuses This is a dangerous practice Such wire has too high a rating and will not protect you against a short circuit or overload

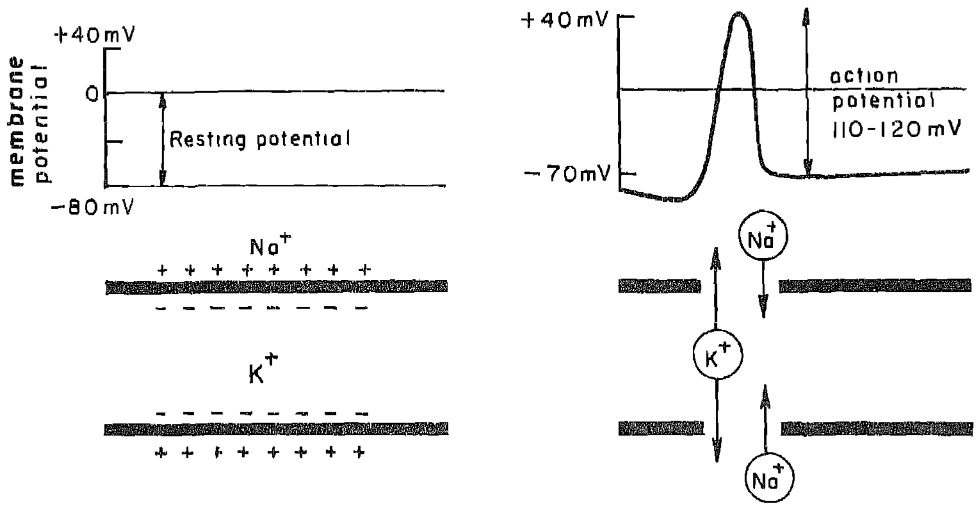
5 The fuse and switches should always be connected to live wire in case of A C. circuit The earth wire must be used while using electrical appliances. One should not touch the metallic body of electric appliances like heaters or iron while they are switched on

Despite all precautions, it is possible that someone accidentally contacts a live wire If this happens, one should try to provide such a person with support of some non-conducting material like wood, plastic or rubber One should never try to pull away a person who has contacted the live wire The first step, of course, is to switch off the current at once

14 13 Electricity in the Body

As you will read in Chapter 19 of this book, the nervous system in animals operates using electrical signals Sensory organs such as the eye, ear, skin, nose and mouth register signals from the outside world These signals are translated in the organs into electrical potentials using nerve cells or *neurons* Neurons are specialised cells that even look like electrical wires (see Figure 19 9) Sensory perception leads to the production of an electrical impulse, or action potential, in the neuron This impulse is conducted along nerve fibres to the central nervous system or the brain. They process the signal and send out the response, again as electrical signals to the concerned organ for action At this organ, the electrical signal is again translated into muscle contraction or other relevant response.

How does a neuron produce electricity? Figure 14 22 illustrates the principle behind this phenomenon Normally, or in the resting state, the neuron is rich in K^+ ions inside and has a lower concentration of Na^+ than the outside medium This concentration difference creates a p.d between the outside and the cell of −0 070 V The cell is negative with respect to the outside When the action potential is triggered by the photoreceptor in the retina, the taste receptors of the mouth, the smell receptors of the nose, receptors of the skin or motor action of the muscle, the neuron "fires" A "gate" opens and lets Na^+ ions pour into the cell This makes the cell electrochemically imbalanced and positive with respect to the outer medium The potential changes from −0 070 V to + 0 040 V or a total change of about 0 110 - 0 120 V This is the electrical impulse of the neuron The impulse is caused by the operation of an ion pump system, called the Na^+, K^+ ATPase enzyme system In the wake of the impulse, K^+ are pumped out and the normal negative potential is restored The impulse or action potential travels from one neuron to another through junctions called synapses at the speed of about 25 m/s, to the brain for processing and reaction The neuron is thus a biological electrochemi-



(a)

RESTING

Na^+ excess outside

K^+ excess inside

Potential −70 mV

(b)

ACTION

Na^+ pours in

K^+ goes out

Potential +40 mV

Fig. 14.22

cal cell, described in Chapter 5, section 3.

Some organisms not only employ the electrochemical mechanism for their own use, but use it as a weapon for attack. The fish called the *electric eel* and the *electric ray* impart very powerful electric shocks to their victims and stun them before eating them. An electric eel is known to discharge 700 V and 1 ampere direct current electrical pulse at short intervals. This becomes possible due to the presence of over 6000 special cells called *electrocytes* in the eel's body, each of which can generate 0.1 V and all of which can discharge in synchrony. Unlike the neurons, an electrocyte is a flattened cell. Its upper face increases Na^+ entry upon firing while the lower face behaves normally. This leads to a discharge from the organism to the outside. Of course, the eel protects itself from its own discharge by the use of efficient insulators (fats, blubber) on its skin and beneath

NAMING UNITS AFTER SCIENTISTS

We honour great men by naming places and institutions after them. Gandhinagar, Washington, Prakasam district, Jawaharlal Nehru University, Sardar Patel High School, Ferozshah Kotla Grounds and Indira Gandhi Airport are some examples This practice has been followed for quite some time in science Here, units of some properties and quantities are named after pioneering scientists The field of electricity and magnetism in particular is rich in such honours to the great men who have contributed to this area of science Here are some examples from this chapter

1 Andre Marie *Ampere*, 1775-1836, French physicist, after whom the unit of current is named

2 Charles Augustin de *Coulomb*, 1736-1806, also French, after whom the unit of electric charge is named

3 Michael *Faraday* 1791-1867, English physicist and chemist Started his career as a laboratory assistant and washed bottles in Humphrey Davy's laboratory He was the discoverer, along with Joseph Henry of USA, of electromagnetic induction He was also an originator of electrochemistry as a subject He coined the term 'ion' that we use today

   Two units are named after him One is the *faraday* (F), which is 96500 coulomb and equals one mole of electrons The other is the *farad*(F), the unit of electrical capacitance, i e the change in the number of coulomb per volt change of potential

4 Joseph *Henry*, 1797-1878, physicist from the USA, who discovered electromagnetic induction independently of Faraday The *henry* (H) is the unit of electric inductance, the property of a circuit by which a change in current of 1 ampere per second produces an electromotive force or potential of 1 volt

5 James Prescott *Joule*, 1819-1889, the English Physicist who was a student of John Dalton gave the first explanation of the law of conservation of energy The *joule* (J) is a unit of work or energy

6 James Clark *Maxwell*, 1831-1879, the Scottish physicist who showed that electricity and magnetism are interrelated The famous Maxwell equations form the basis of our understanding of electromagnetic phenomenon even today After him is named the *maxwell*, the unit of magnetic flux.

7 Hans *Oersted*, 1777-1851, the Danish physicist who performed the experiment shown in Figure 14 8 An *oersted* (Oe) is a unit of magnetic field intensity.

   Two related units are the *gauss* (G), named after the great German genius Karl Friedrich Gauss (1777-1855) and the *tesla* (T), after the Italian physicist of the same name 1T = 10000 G and 1G = 1 maxwell/cm^2

8 Georg Simon *Ohm*, 1787-1854, the German scientist after whom the unit of electrical resistance is named

9 Alessandro *Volta*, 1745-1827, Professor of Physics at the University of Pavia in Italy He invented the electric cell by connecting zinc and silver rods through a cloth wetted with salt solution and producing an electric current Several of these joined together make a *voltaic* pile or a battery of cells. These piles were used extensively by Davy and others to isolate elements like K and Na through

electrolysis It was Volta who could properly explain Luigi Galvani's discovery of a dead frog's leg twitching when contacted with copper and iron pieces. He said that this is the property of the metals and not 'animal electricity' The *volt* (V) is named after him

10. James *Watt*, 1736-1819, the British engineer and inventor of the steam engine His patent of the steam engine in 1769 ushered in the factory system and the Industrial Revolution in Britain The unit of power, a *watt* (W) is, as you know a joule per second

Amusingly, we use prefixes such as milli-,mega- and so on to these names and do not even think twice about it Are the kilowatt (kW) or the picofarad(pF) not what the English teacher would call mixed metaphors or hybrid words? There are many other such units and prefixes too Do you know these-einstein (E), millinewton (mN), gigahertz (GHz), kilodalton (kD), roentgen, debye, microcurie (μc), fermi? Can you give further examples of such name units?

IN THE LANGUAGE OF MATHEMATICS

If we denote

V = Voltage (potential difference, p d) in volt
Q = Charge in coulomb
I = Current in ampere
W = Work in joule
t = Time
R = Resistance in ohm
P = Power
$Q = It$ $V = I.R$ $W = VQ$
$W = VIt$ $W = I^2Rt$ $W = Pt$
$P = VI$ $P = I^2R$

Resistances in series

$$R = R_1 + R_2 + R_3 + \ldots$$

and in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

QUESTIONS

Choose the right answers -

1 The work done in moving a unit positive charge across two points in an electric circuit is a measure of
(a) current
(b) potential difference
(c) resistance.
(d) power

2 The device used for measuring potential difference is known as
  (a) potentiometer
  (b) ammeter
  (c) galvanometer
  (d) voltmeter

3 Electromagnetic induction is involved in
  (a) charging a body with a positive charge
  (b) production of current by relative motion between a magnet and the coil
  (c) rotation of the coil of an electric motor
  (d) generation of magnetic field due to a current carrying soleniod

4 An electric generator actually acts as
  (a) a source of electric charge
  (b) a source of heat energy
  (c) an electromagnet
  (d) a converter of energy

5 What are the conditions under which charges can move in a conductor?

6 How is the potential difference maintained across the ends of a conductor?

7 What will be the current drawn by an electric bulb of 40 W when it is connected to a source of 220 V?

8 A simple electric circuit has a 24 V battery and a resistor of 60 ohm What will be the current in the circuit? The resistance of the connecting wires are negligible

9 Explain the principle of working of an electric motor with the help of a diagram

10 The values of current I flowing through a coil for the corresponding values of the potential differene V across the coil are shown below

I ampere	0 05	0 10	0 20	0 30	0 4
V volt	0 85	1 70	3 5	5 0	6 8

Plot a graph between V and I and calculate the resistance of the coil

11. State Ohm's law

12 Describe an experiment to show that a current-carrying conductor experiences a force in a magnetic field and that the direction of force depends on the direction of (a) the magnetic field,and (b) the current

13 A coil of copper wire is connected to a galvanometer What would happen if a bar magnet is
  (a) pushed into the coil with its north pole entering first?
  (b) held at rest inside the coil?
  (c) pulled out again?

14 With the help of a labelled diagram explain the principle underlying the working of an electric generator

15 A current of 4 A flows through a 12 V car headlight bulb for 10 minutes How much energy transfer occurs during this time?

16 Calculate the energy transferred by a 5 A current flowing through a resistor of 2 ohm for 30 minutes

17 An electrical heater is used on a 220 V supply and takes a current of 5 ampere

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(a) What is its power?
(b) *What is the cost of using the heater if 1 kWh costs 50 paise*

18 For a heater rated at 4 kW and 220 V, calculate
(a) the current,
(b) the resistance of the heater,
(c) the energy consumed in 2 hours, and
(d) the cost if 1 kWh is priced at 50 paise

19 Electricians wear rubber sandals or shoes or rubber handgloves while working Why?

20 Many electrical appliances and circuits are "earthed" or "grounded" What is the reason for this?

21 What is the difference between an electromagnet and a permanent magnet?

22 Make a list of at least five hydro and five thermal power stations in India Where are these located? Indicate them on the map of India

23 What is the usual colour code followed for connecting live, neutral and earth wires? Why is it so important?

24 Explain what is meant by overloading in an electric supply How can it be prevented?

25 Describe an experiment to explain the action of an electric fuse.